Quantifying the Health Effects of Air Pollution Globally

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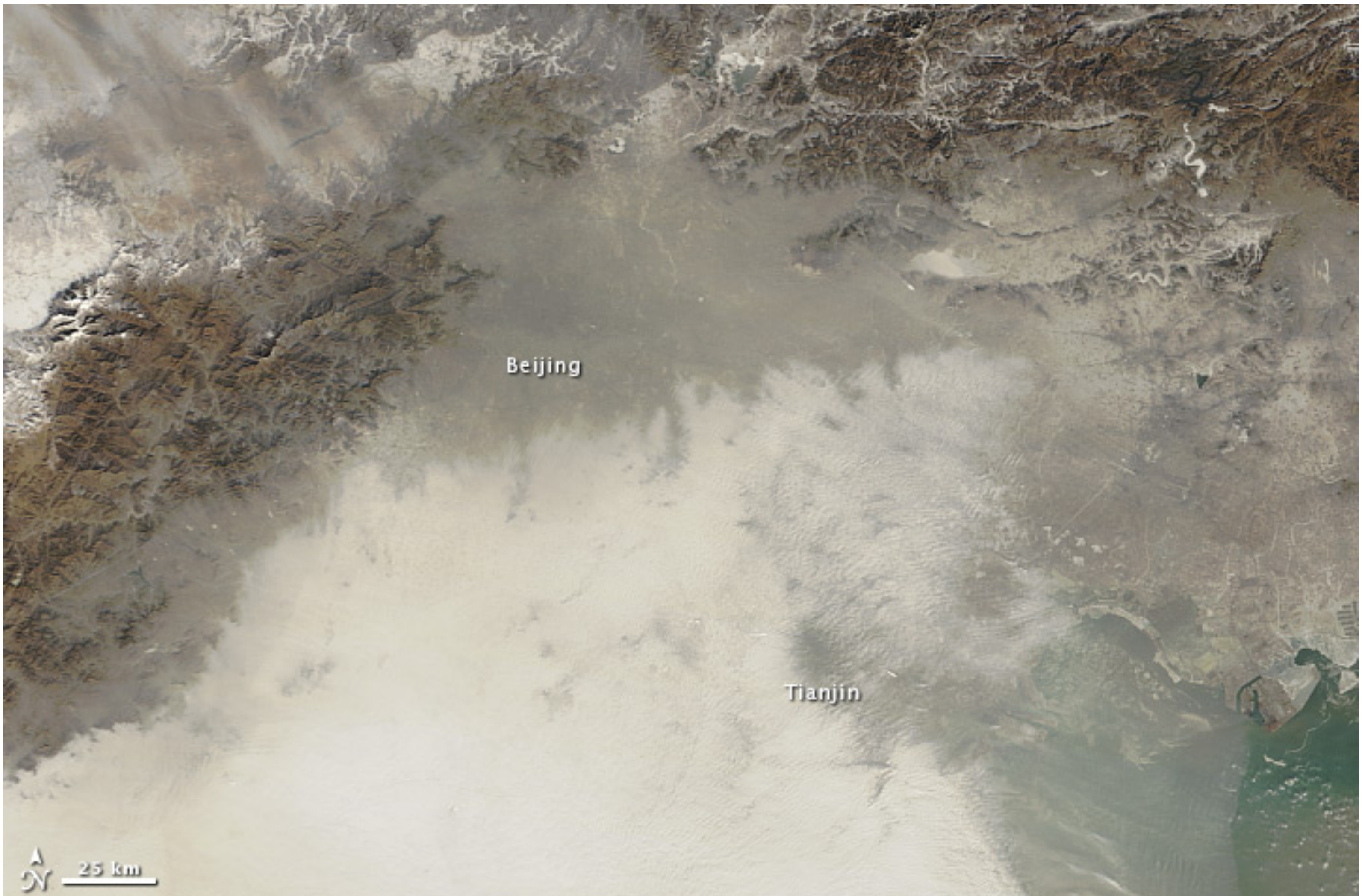
Beijing – January 14, 2013
Some stations reported >500 μg m^{-3} 24-hr avg. $PM_{2.5}$ (>20 times the WHO guideline)

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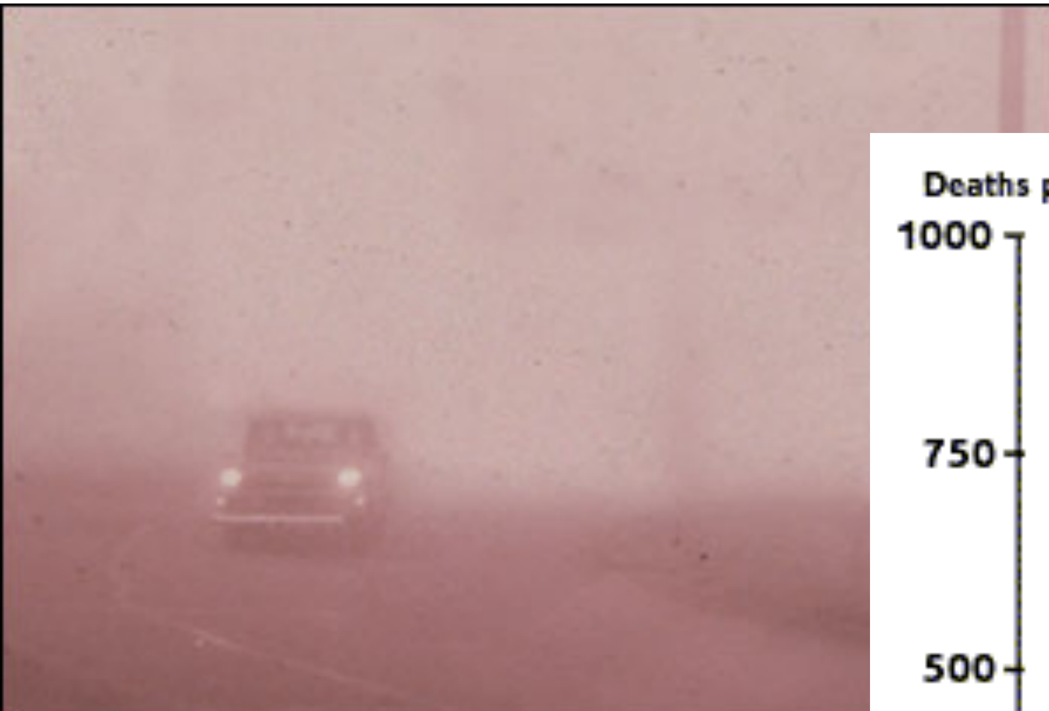
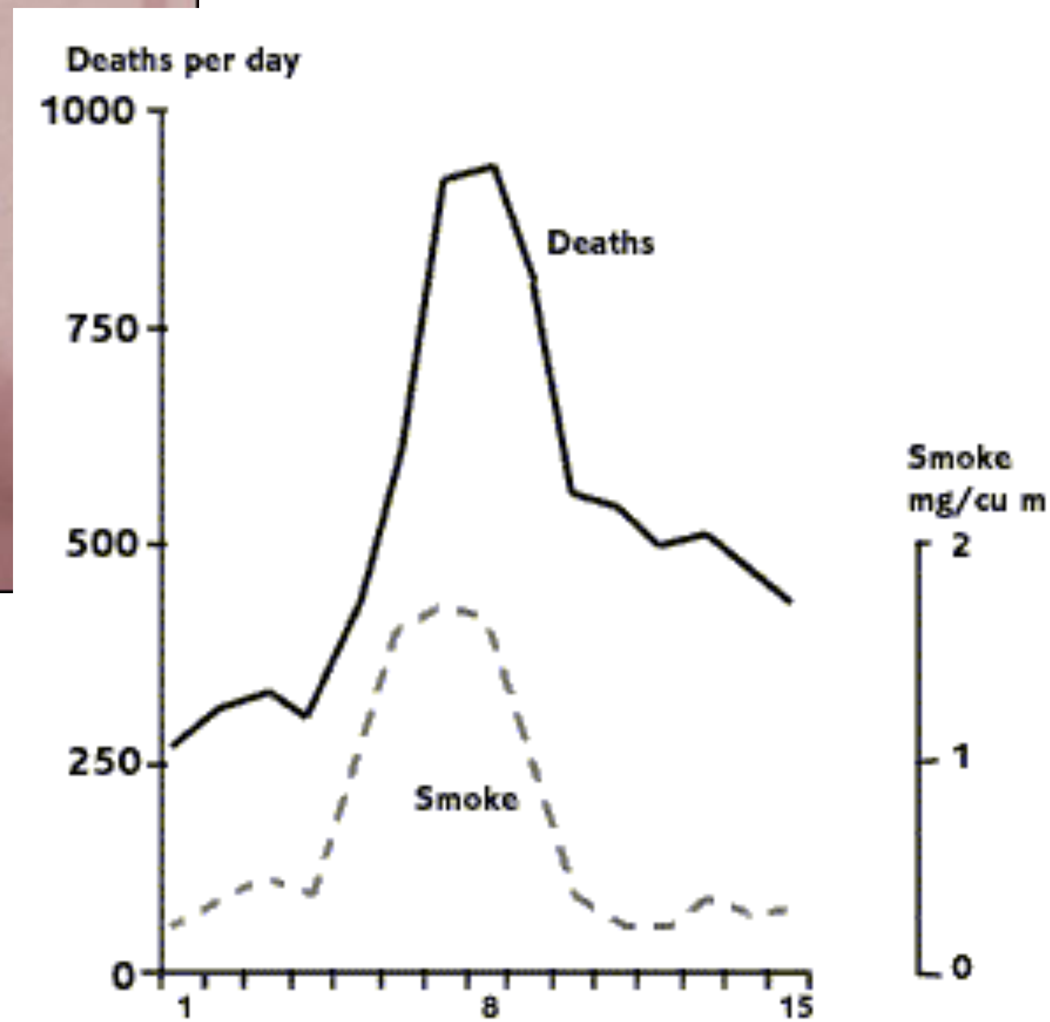
Delhi, Nov. 6, 2018

91% of the global population lives in areas with ambient $PM_{2.5}$ concentrations that violate WHO's guideline (10 μg m^{-3} annual average)

London, 1952





Deaths per day
1000
750
500
250
0
Deaths
Smoke
Smoke
mg/cu m
2
1
0
1
8
15

Harvard Six-Cities Study (Dockery et al., 1993):

First long-term cohort study of chronic mortality.

~8000 adults followed over many years.

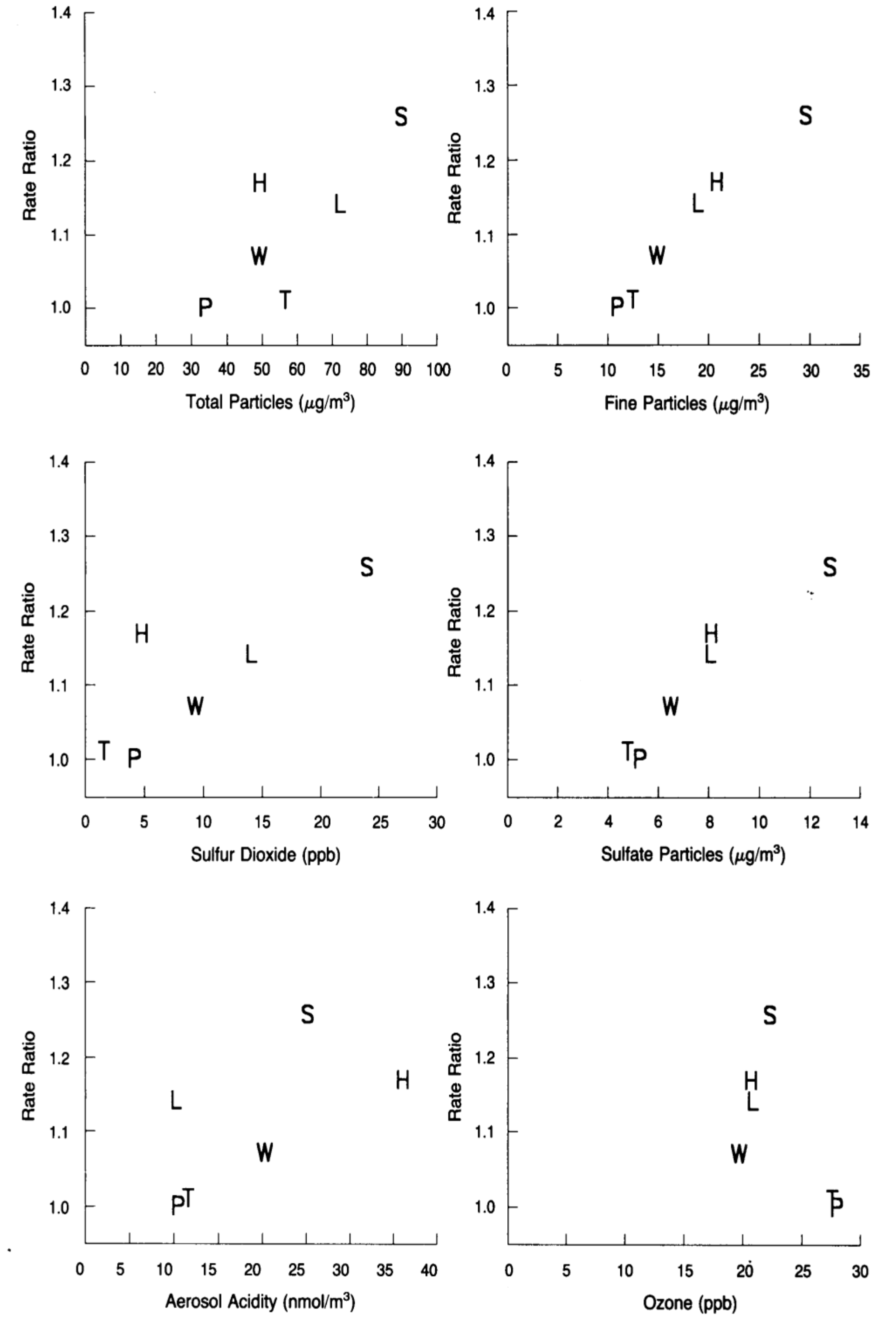


Figure 3. Estimated Adjusted Mortality-Rate Ratios and Pollution Levels in the Six Cities.

Mean values are shown for the measures of air pollution. P denotes Portage, Wisconsin; T Topeka, Kansas; W Watertown, Massachusetts; L St. Louis; H Harriman, Tennessee; and S Steubenville, Ohio.

New York Times

MONDAY, JULY 19, 1993

STUDIES SAY SOOT KILLS UP TO 60,000 IN U.S. EACH YEAR

CALL TO REDIRECT EFFORTS

Little Is Spent on Particles That Harm Mostly Young, Elderly and Those With Asthma

By PHILIP J. HILTS

Special to The New York Times

WASHINGTON, July 18 — Several studies have concluded that tens of thousands of deaths are being caused in the United States each year by a form of air pollution that for the most part falls within current legal limits: tiny particles of soot that are inhaled.

Rough calculations emerging from studies at the Environmental Protection Agency and the Harvard School of Public Health suggest that 50,000 to 60,000 deaths a year are caused by the particle pollution, a far larger number than any other form of pollution and one that rivals the death toll from some cancers.

The deaths occur mostly among children with respiratory problems, people of all ages with asthma and the elderly with illnesses like bronchitis, emphysema and pneumonia.

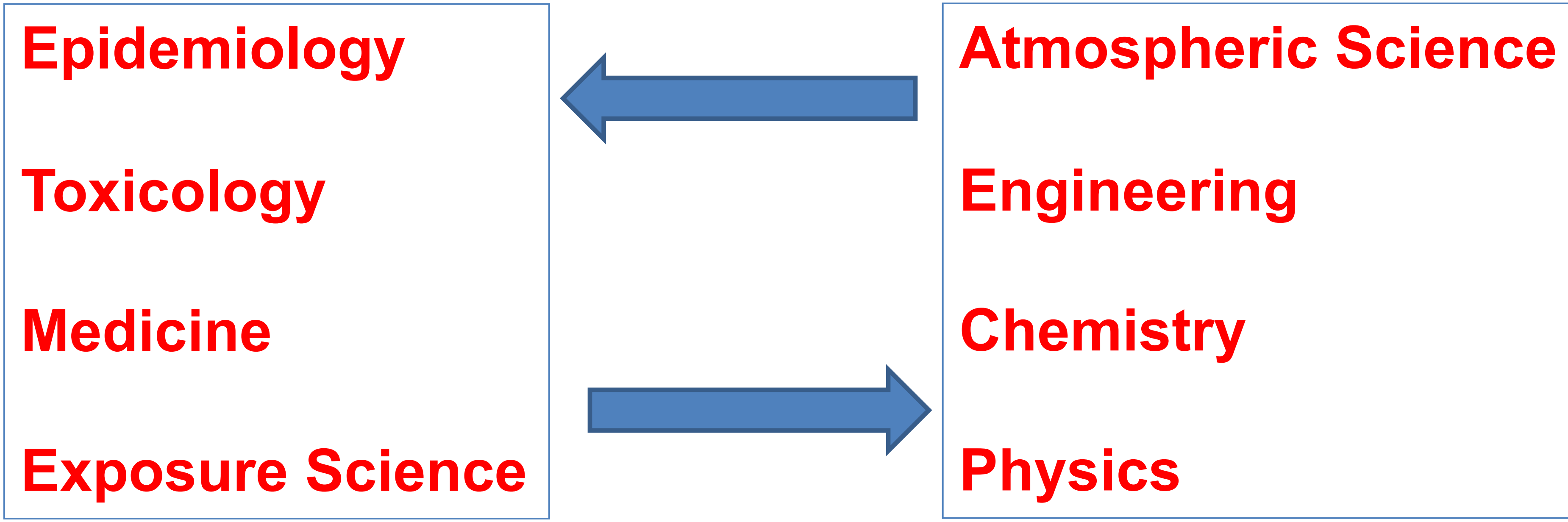
Air Pollution & Health Motivating Questions

1) What specific characteristics and components or specific mixtures are responsible for specific health impacts?

2) How important are specific source sectors or regions for health impacts in a given region?

3) Would other indicators of the pollutant mixture be more effective for managing air pollution health impacts?

4) What are health impacts associated with different energy and emission control scenarios?


Epidemiology
Toxicology
Medicine
Exposure Science
Atmospheric Science
Engineering
Chemistry
Physics

Epidemiology

Toxicology

Medicine

Exposure Science

Atmospheric Science

Engineering

Chemistry

Physics

- **Measurements of chemical components**
- **Spatially-distributed measurements (cheap sensors)**
- **Satellite observations**
- **Computer models**

Epidemiology

Toxicology

Medicine

Exposure Science

Atmospheric Science

Engineering

Chemistry

Physics

- **Which pollutants to emphasize, averaging times**
- **Risk functions**
- **Biological mechanisms**

Environmental Science & Technology

Feature

pubs.acs.org/est

"What We Breathe Impacts Our Health: Improving Understanding of the Link between Air Pollution and Health"

J. Jason West,[*,†] Aaron Cohen,[*,‡] Frank Dentener,[*,§] Bert Brunekreef,[||] Tong Zhu,[*,⊥] Ben Armstrong,[#] Michelle L. Bell,[∇] Michael Brauer,[○] Gregory Carmichael,[◆] Dan L. Costa,[¶] Douglas W. Dockery,[★] Michael Kleeman,[⊗] Michal Krzyzanowski,[⋈] Nino Künzli,[☼,◑] Catherine Liousse,[◊] Shih-Chun Candice Lung,[@] Randall V. Martin,[¢,$] Ulrich Pöschl,[♁] C. Arden Pope, III,[¥] James M. Roberts,[%] Armistead G. Russell,[€] and Christine Wiedinmyer[Я]

- Air pollution is underappreciated for global health.
- Air pollution and its health impacts are changing globally, and will change in ways interrelated with climate change.
- Air pollution science offers new possibilities: new measurement methods measuring more chemical components, cheap sensors that can be widely deployed, satellites, and models.
- There is a need for the communities of air pollution science and air pollution health effects science to work together better.

Health impact function

$$\Delta Mort = y_0 \text{ x } AF \text{ x } Pop$$

$$\Delta Mort = y_0 \text{ x } (1\text{-}exp^{-\beta \Delta X}) \text{ x } Pop$$

Baseline mortality rate

Exposed Population

ΔX = Change in concentration

β = Concentration-response factor

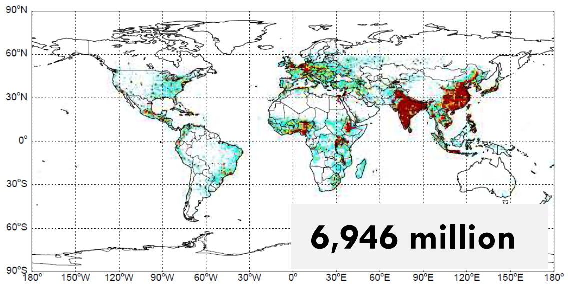
(≈ CPD)

- **Respiratory diseases** (RESP) (inc. COPD – chronic obstructive pulmonary disease)
- **Cardiovascular diseases** (inc. IHD – ischemic heart disease, STROKE – cerebrovascular disease)

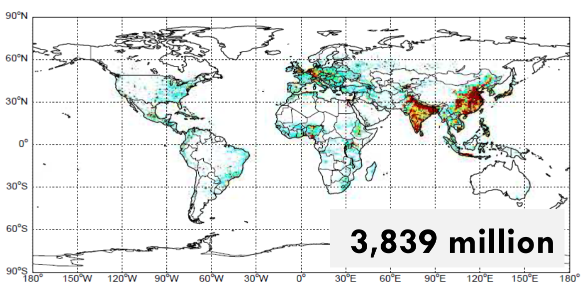
- **Lung Cancer** (LC)

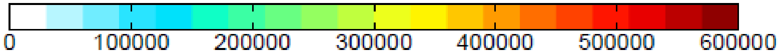
Population and Baseline Mortality Rates

Total Population, **persons**
(Landscan 2011 at 30"x30"
gridded to 0.67°x0.5°)



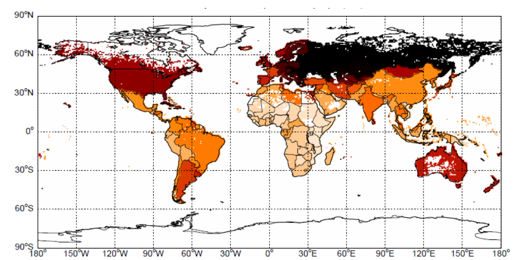
Population 25+, **persons**
(Landscan 2011 at 30"x30"
gridded to 0.67°x0.5°)



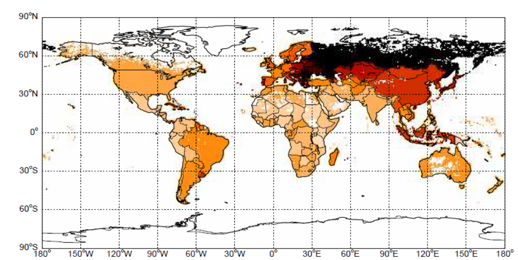


Baseline Mortality Rates, **deaths per year per 100,000**
(GBD 2010, country level, AllAges > gridded to 0.67°x0.5°)

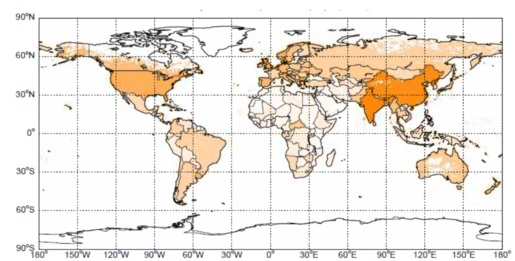
IHD



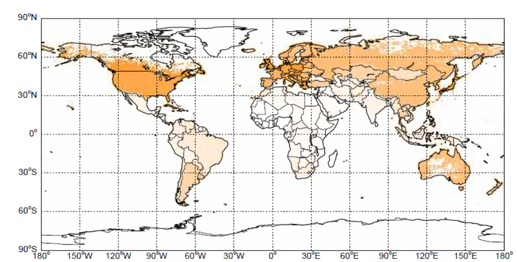
Stroke

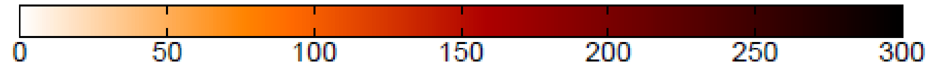


COPD

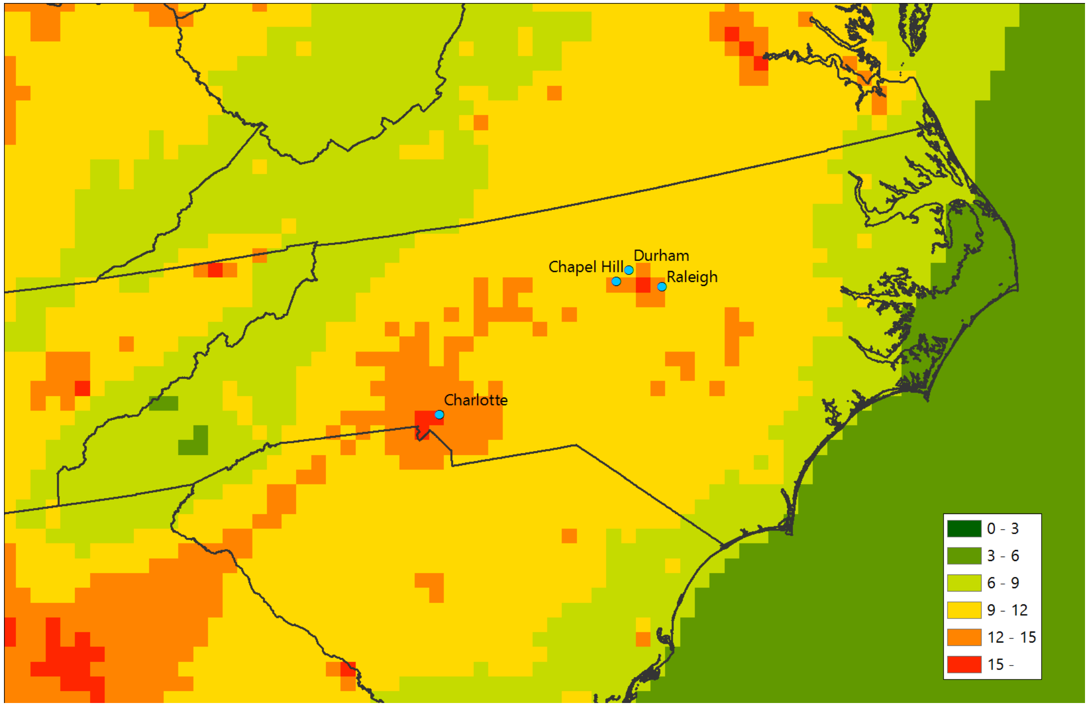


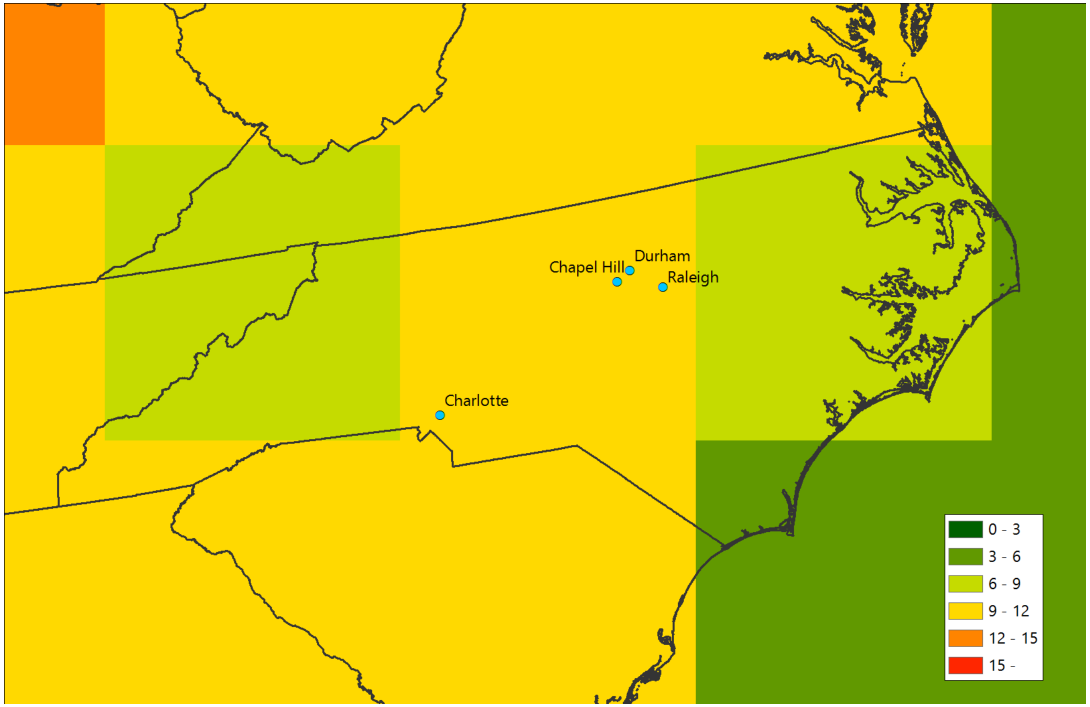
LC





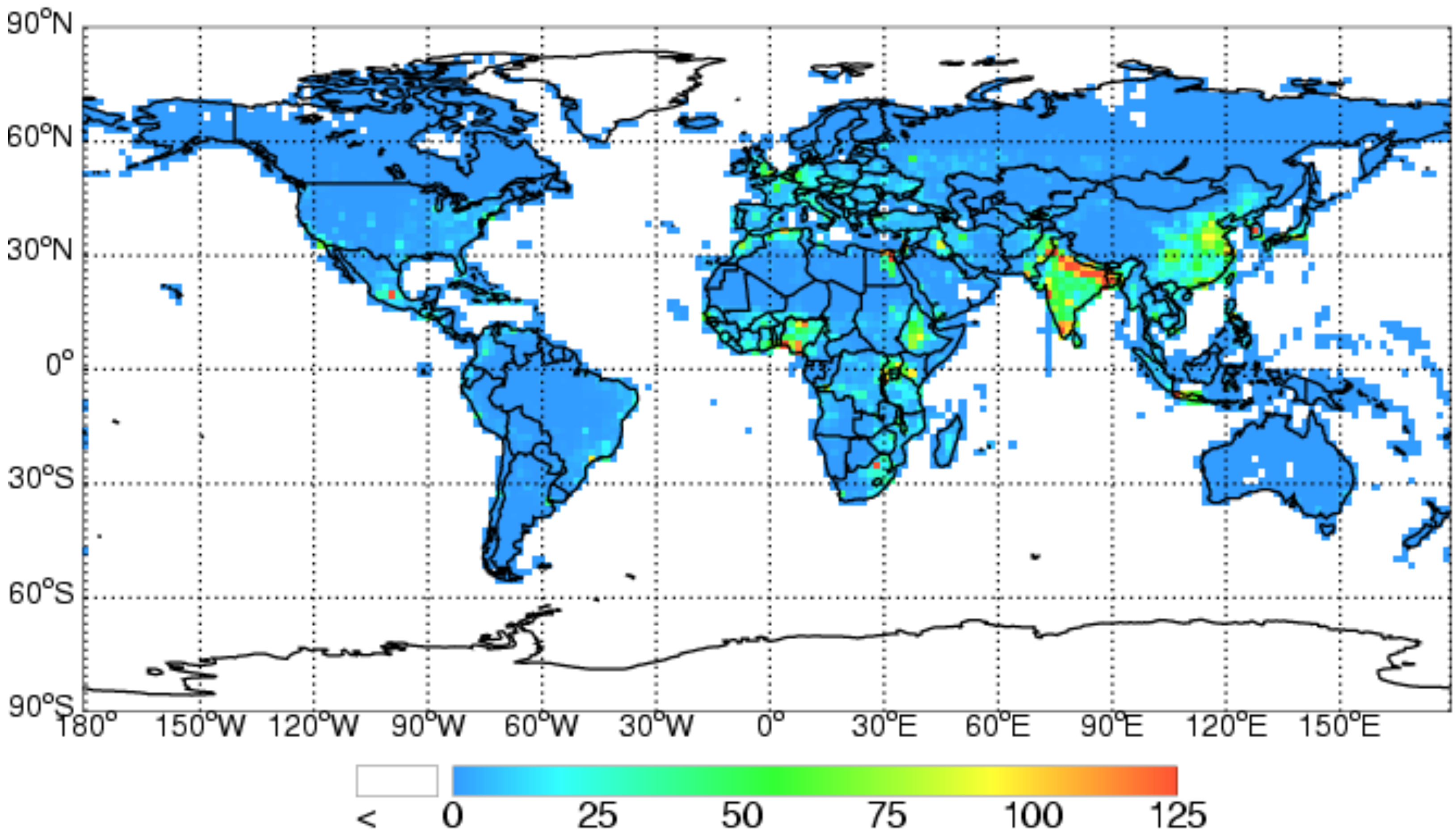
12-km CMAQ





Global model
2.8° resolution

-20% Global Anthrop. Methane Emissions: 30,200 avoided premature deaths in 2030 due to reduced ozone



West et al., *PNAS*, 2006

Research from my lab

1) How many people die each year due to exposure to ambient air pollution?

2) How will climate change affect global air pollution and air pollution-related deaths?

3) What are trends in air pollution-related deaths in the US?

4) If we slow down climate change, what are the benefits for air pollution and health?

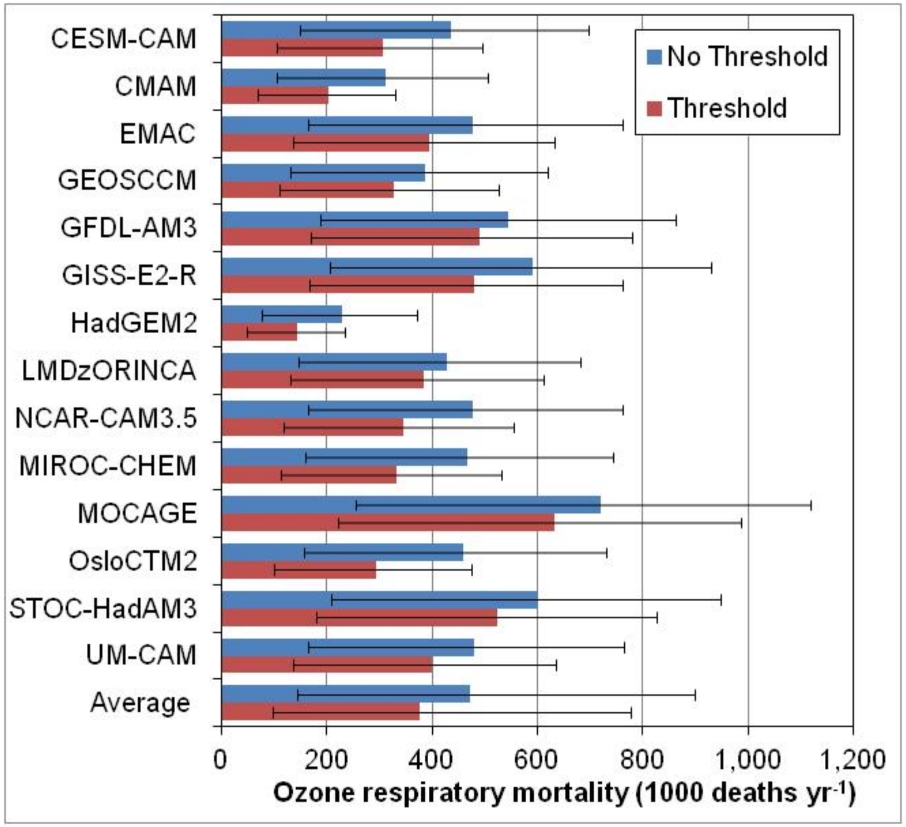
Global mortality burden – ACCMIP ensemble

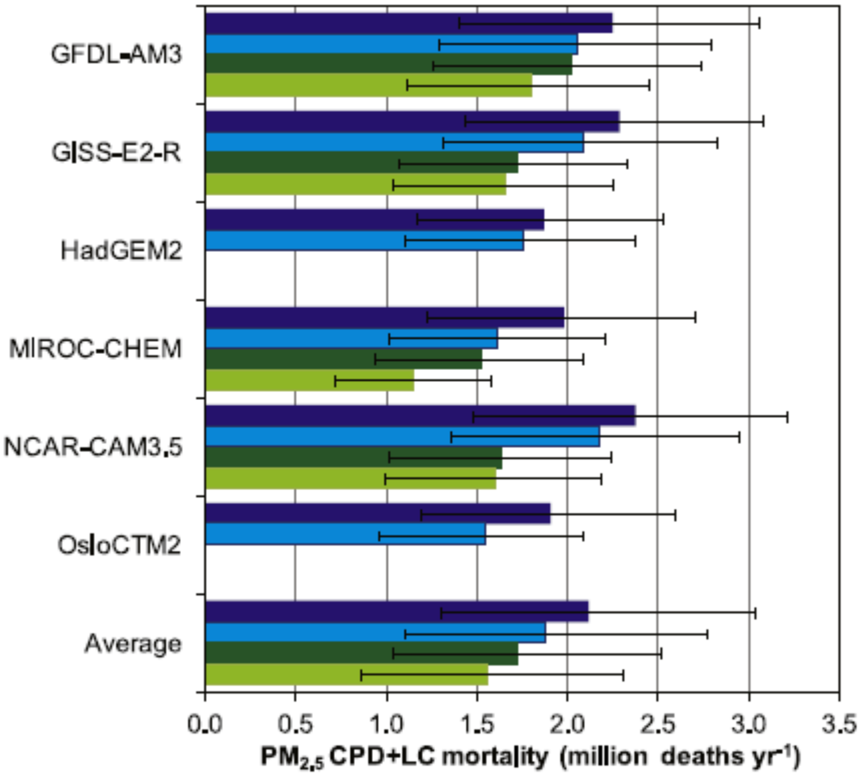
Ozone-related mortality

470,000 (95% CI: 140,000 - 900,000)

$PM_{2.5}$-related mortality(*)

2.1 million (95% CI: 1.3 - 3.0 million)





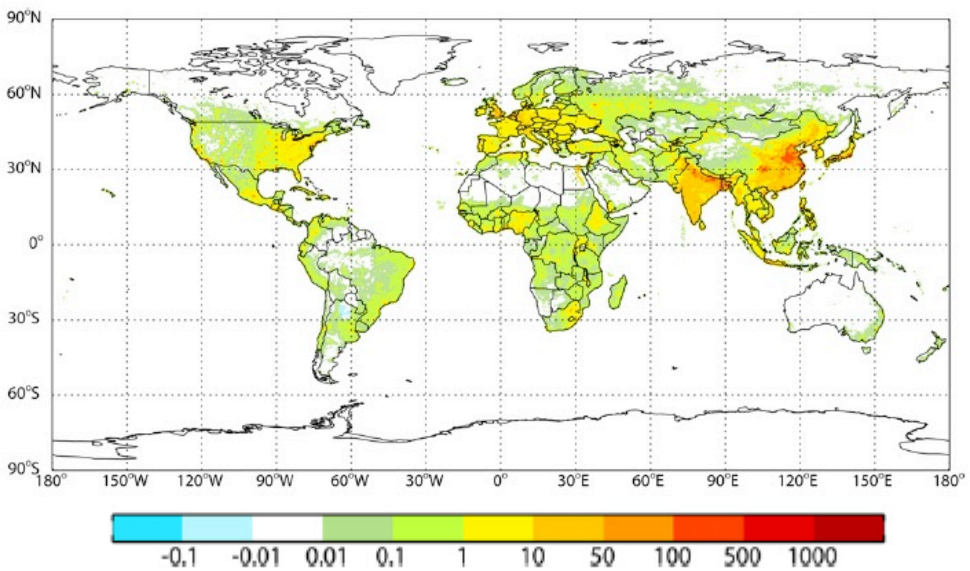
(*) $PM_{2.5}$ calculated as a sum of species (dark blue)
$PM_{2.5}$ as reported by 4 models (dark green)
Light-colored bars - low-concentration threshold (5.8 μg m^{-3})

Global Burden: Ozone-related mortality

Global and regional mortality per year

Regions	Total deaths	Deaths per million people (*)
North America	34,400	121
Europe	32,800	96
Former Soviet Union	10,600	66
Middle East	16,200	68
India	118,000	212
East Asia	203,000	230
Southeast Asia	33,300	119
South America	6,970	38
Africa	17,300	73
Australia	469	29
Global	**472,000**	**149**

(*) Exposed population (age 30 and older)



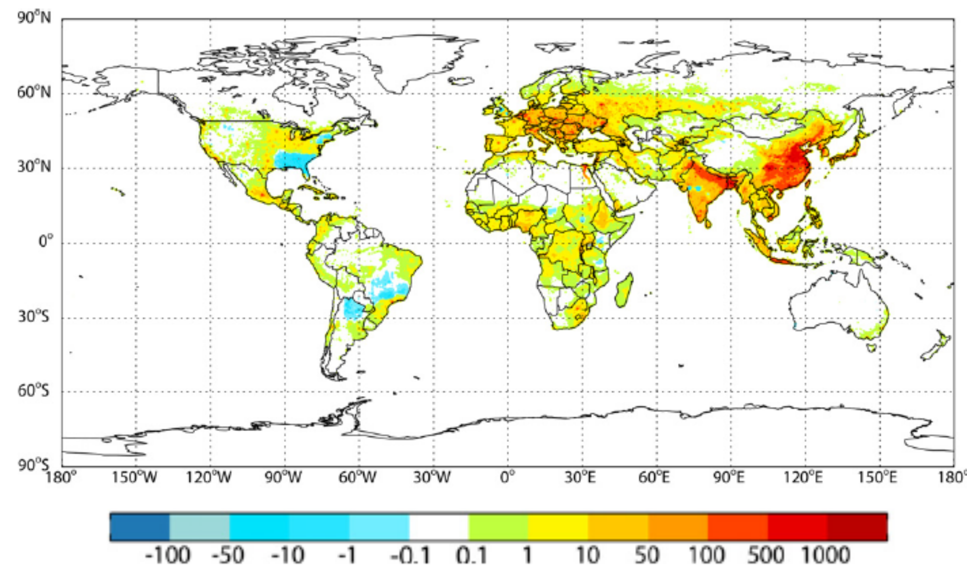
Respiratory mortality , deaths yr^{-1} $(1000\ km^2)^{-1}$, multi-model mean in each grid cell , 14 models

Global Burden: $PM_{2.5}$-related mortality

Global and regional mortality per year

Regions	Total deaths	Deaths per million people (*)
North America	43,000	152
Europe	154,000	448
Former Soviet Union	128,000	793
Middle East	88,700	371
India	397,000	715
East Asia	1,049,000	1,191
Southeast Asia	158,000	564
South America	16,800	92
Africa	77,500	327
Australia	1,250	78
Global	**2,110,000**	**665**

(*) Exposed population (age 30 and older)

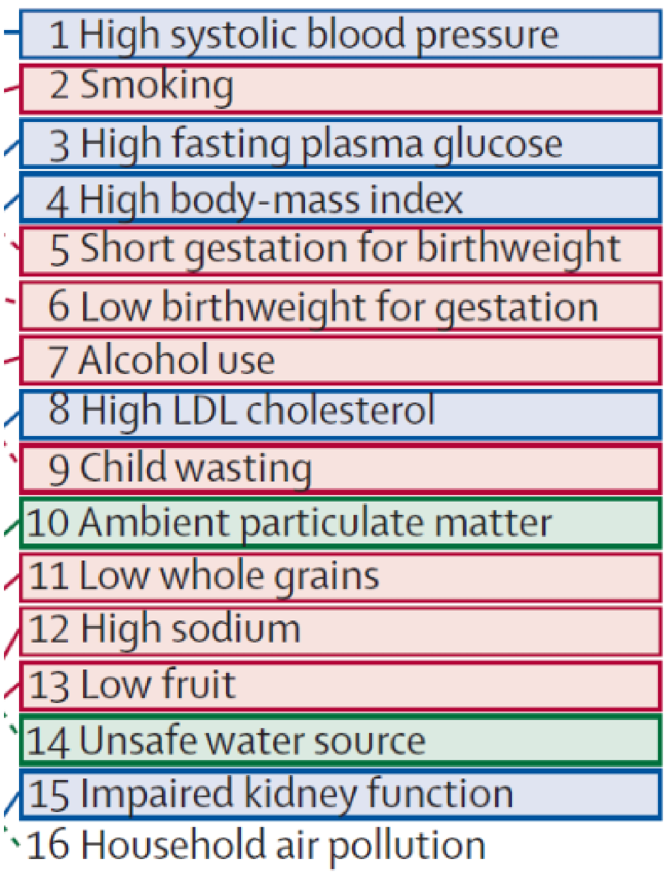


CPD+LC mortality , deaths yr^{-1} $(1000\ km^2)^{-1}$,
multi-model mean in each grid cell , 6 models

Global burden of disease of air pollution (2017)

Global Deaths per Year

Ambient $PM_{2.5}$ pollution:	**2.9 (2.5 – 3.4) million**	**1 in 19 deaths globally!**
Ambient ozone pollution:	**0.47 (0.18 – 0.77) million**	
Household air pollution from solid fuels:	**1.6 (1.4 – 1.9) million**	**1 in 45 deaths globally!**



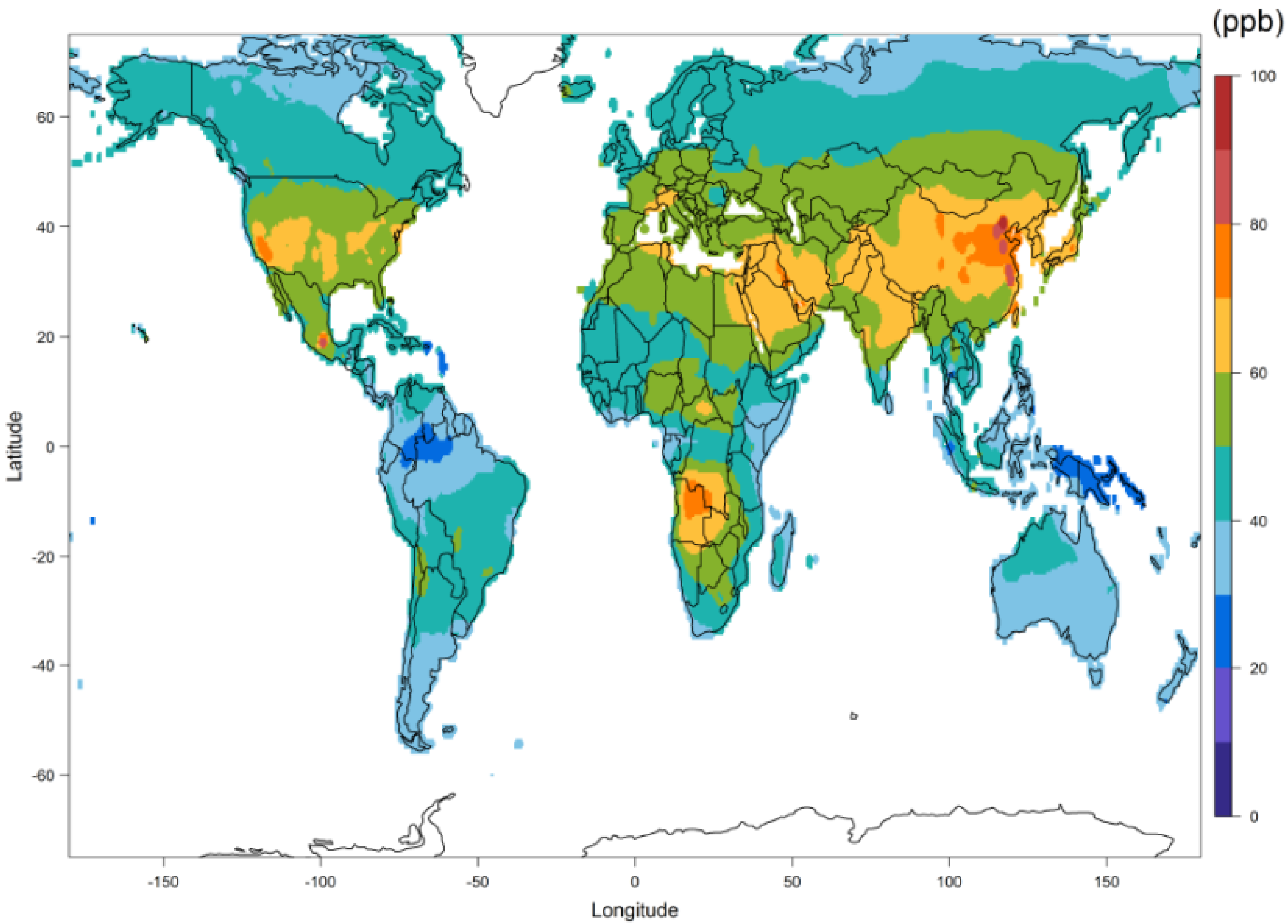
Ambient $PM_{2.5}$ pollution is the 8^{th} leading risk factor for death globally.

GBD 2017 Team, *Lancet*, 2018

A new method (M³Fusion-v1) for combining observations and multiple model output for an improved estimate of the global surface ozone distribution

Geoscientific Model Development
Discussions
Open Access
EGU

Kai-Lan Chang[1, 2], Owen R. Cooper[2, 3], J. Jason West[4], Marc L. Serre[4], Martin G. Schultz[5], Meiyun Lin[6, 7], Virginie Marécal[8], Béatrice Josse[8], Makoto Deushi[9], Kengo Sudo[10, 11], Junhua Liu[12, 13], and Christoph A. Keller[12, 13, 14]



(b) Multi-model composite + bias correction

Global burden of disease of air pollution (2017)

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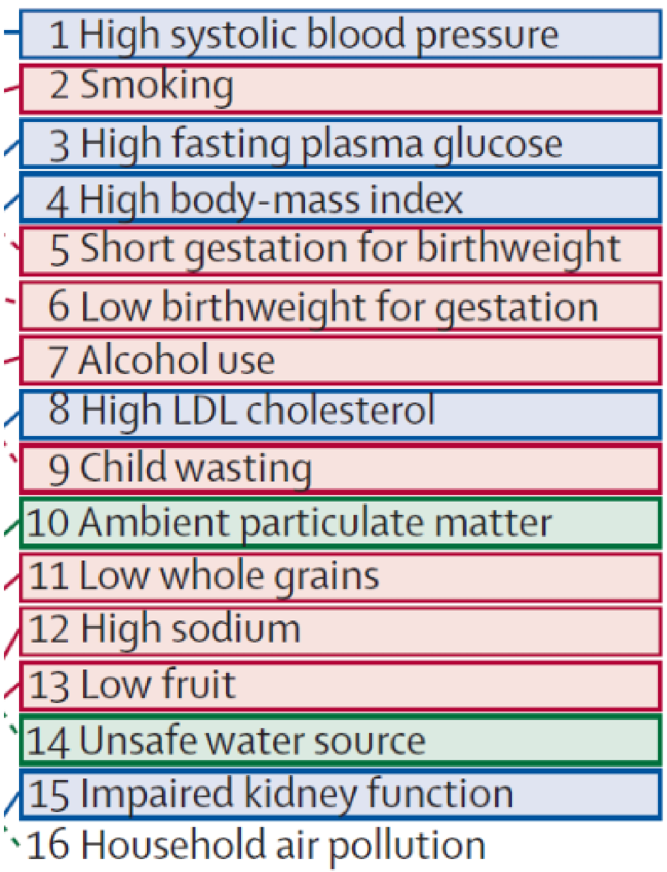

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GBD 2017 Team, *Lancet*, 2018

Global burden of disease of air pollution (2017)

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Ambient ozone pollution:	**0.47 (0.18 – 0.77) million**	
Household air pollution from solid fuels:	**1.6 (1.4 – 1.9) million**	**1 in 45 deaths globally!**

1 High systolic blood pressure
2 Smoking
3 High fasting plasma glucose
4 High body-mass index
5 Short gestation for birthweight
6 Low birthweight for gestation
7 Alcohol use
8 High LDL cholesterol
9 Child wasting
10 Ambient particulate matter
11 Low whole grains
12 High sodium
13 Low fruit
14 Unsafe water source
15 Impaired kidney function
16 Household air pollution

Ambient $PM_{2.5}$ pollution is the 8th leading risk factor for death globally.

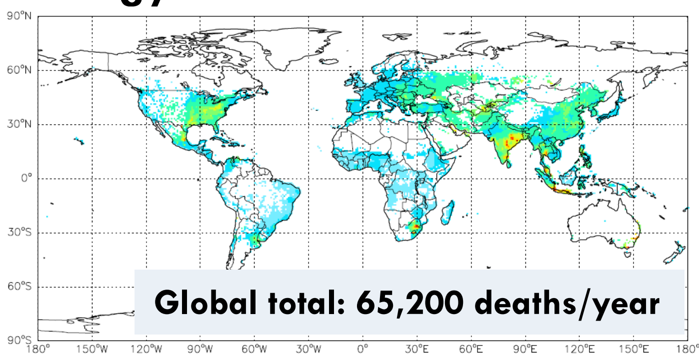
Burnett et al. (PNAS, 2018) estimate 8.9 (7.5-10.3) million deaths from $PM_{2.5}$ in 2015.

GBD 2017 Team, *Lancet*, 2018

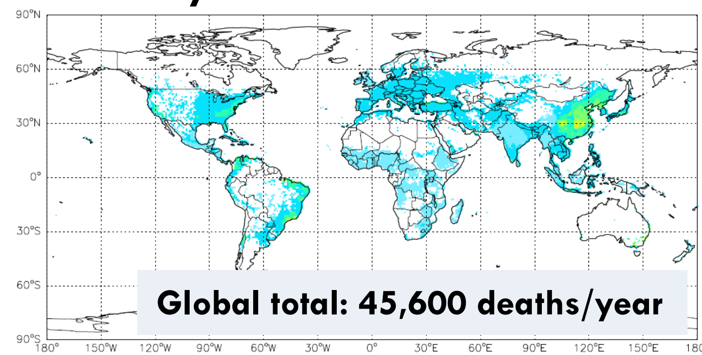
Ozone-related mortality (sectors zeroed-out)

Contributions of each sector to total ozone respiratory mortality,
fraction of total burden in each cell

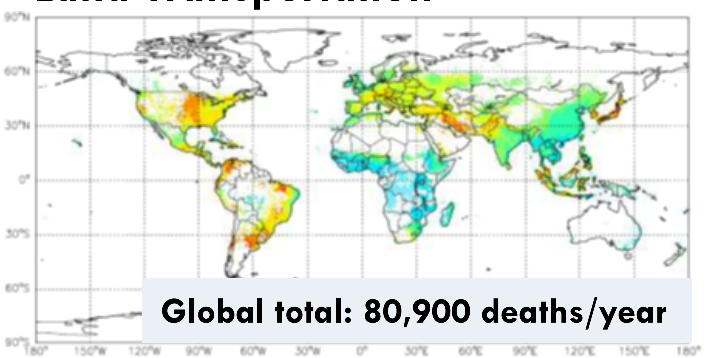
Energy



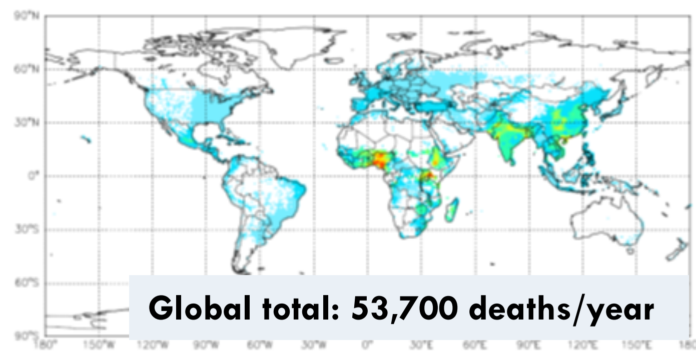
Industry

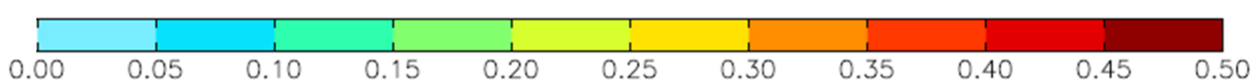


Land Transportation



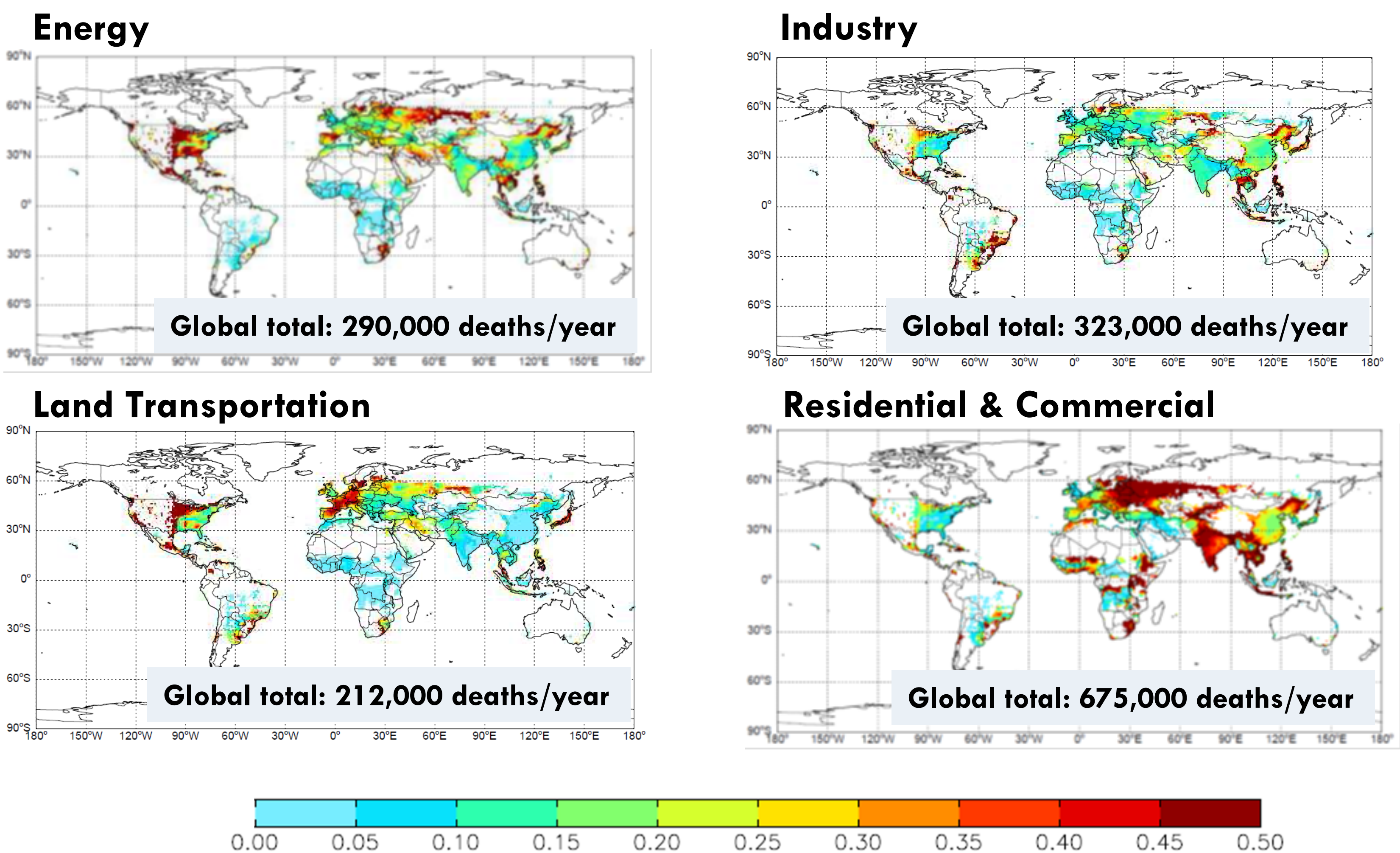
Residential & Commercial





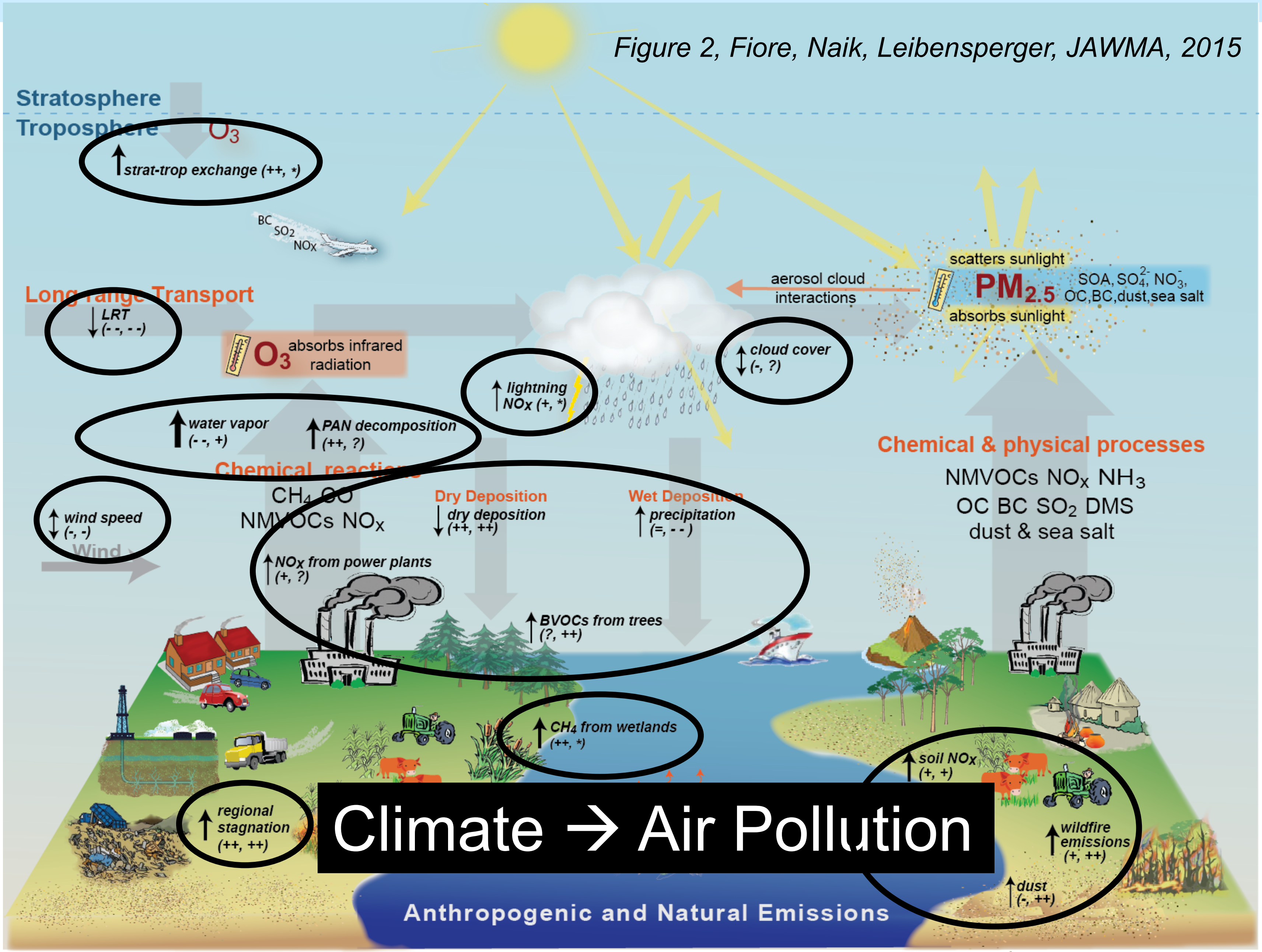
PM$_{2.5}$-related mortality (sectors zeroed-out)

Contributions of each sector to total PM$_{2.5}$ mortality (IHD+Stroke+COPD+LC),
fraction of total burden in each cell



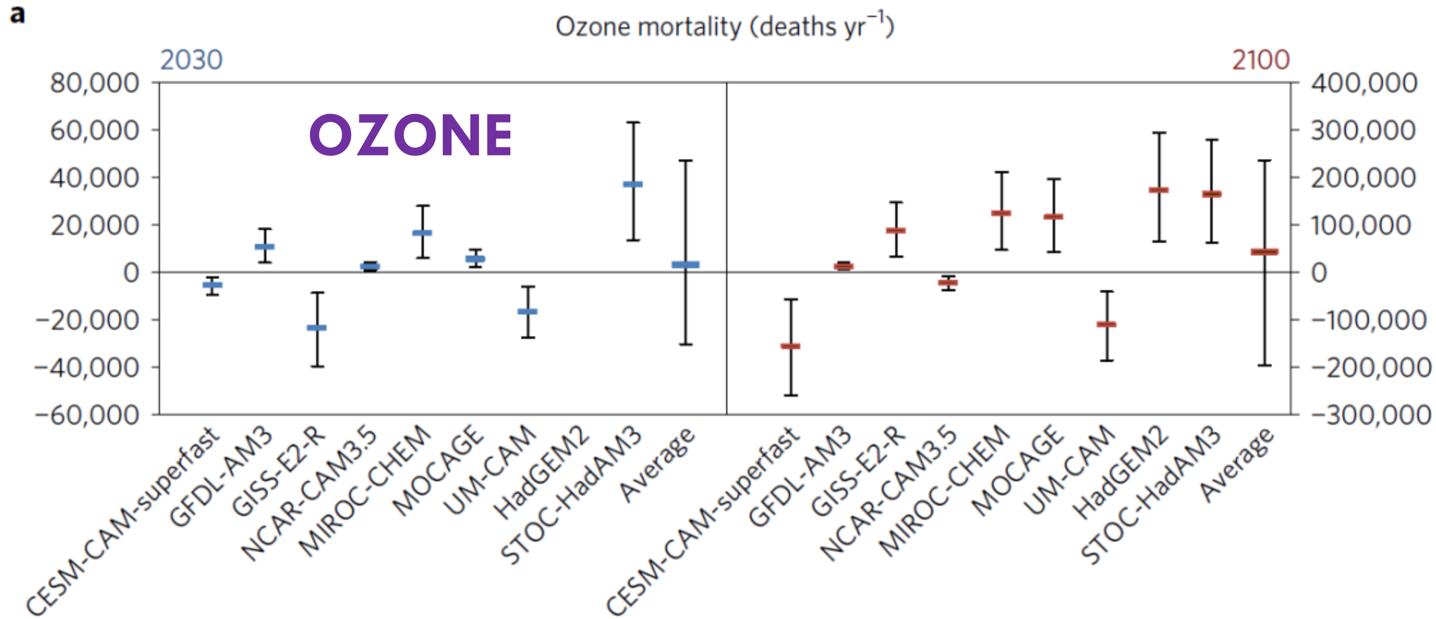
Silva et al. (EHP, 2016)

Summary schematic of air quality-climate connections



Climate → Air Pollution

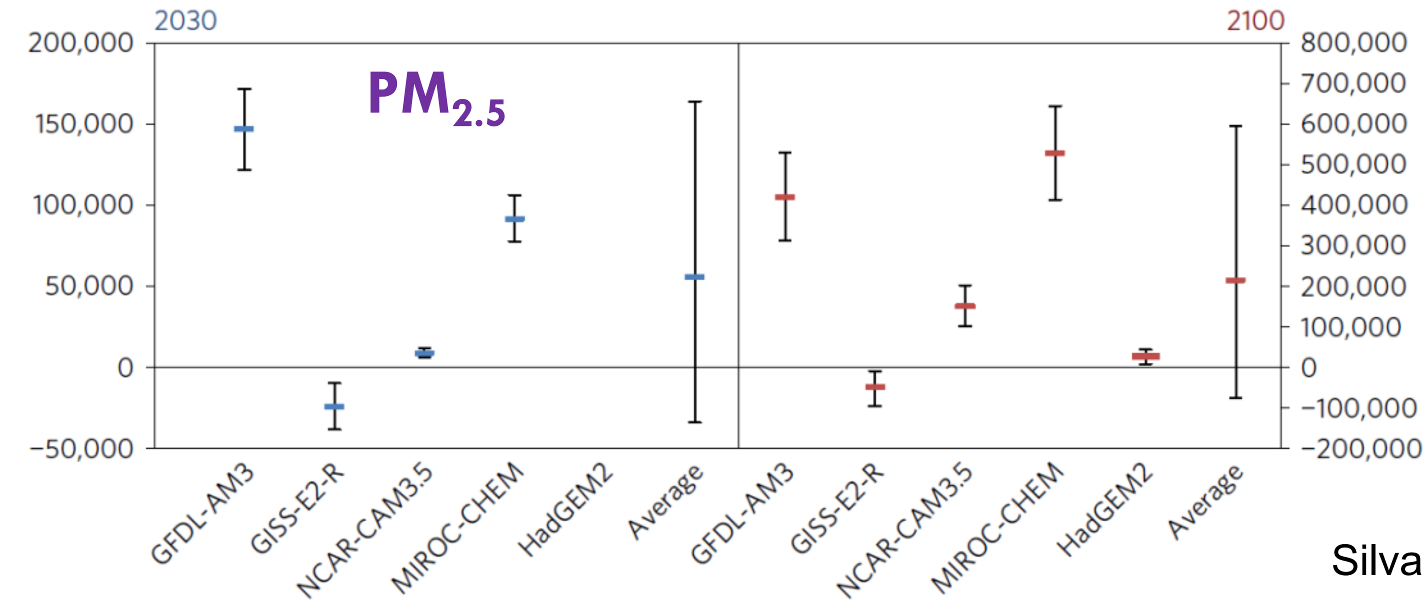
Impact of RCP8.5 Climate Change on Global Air Pollution Mortality: ACCMIP Models



Mean (95% CI)
(deaths yr^{-1})

2030
3,000
(-30,000, 47,000)

2100
44,000
(-195,000, 237,000)



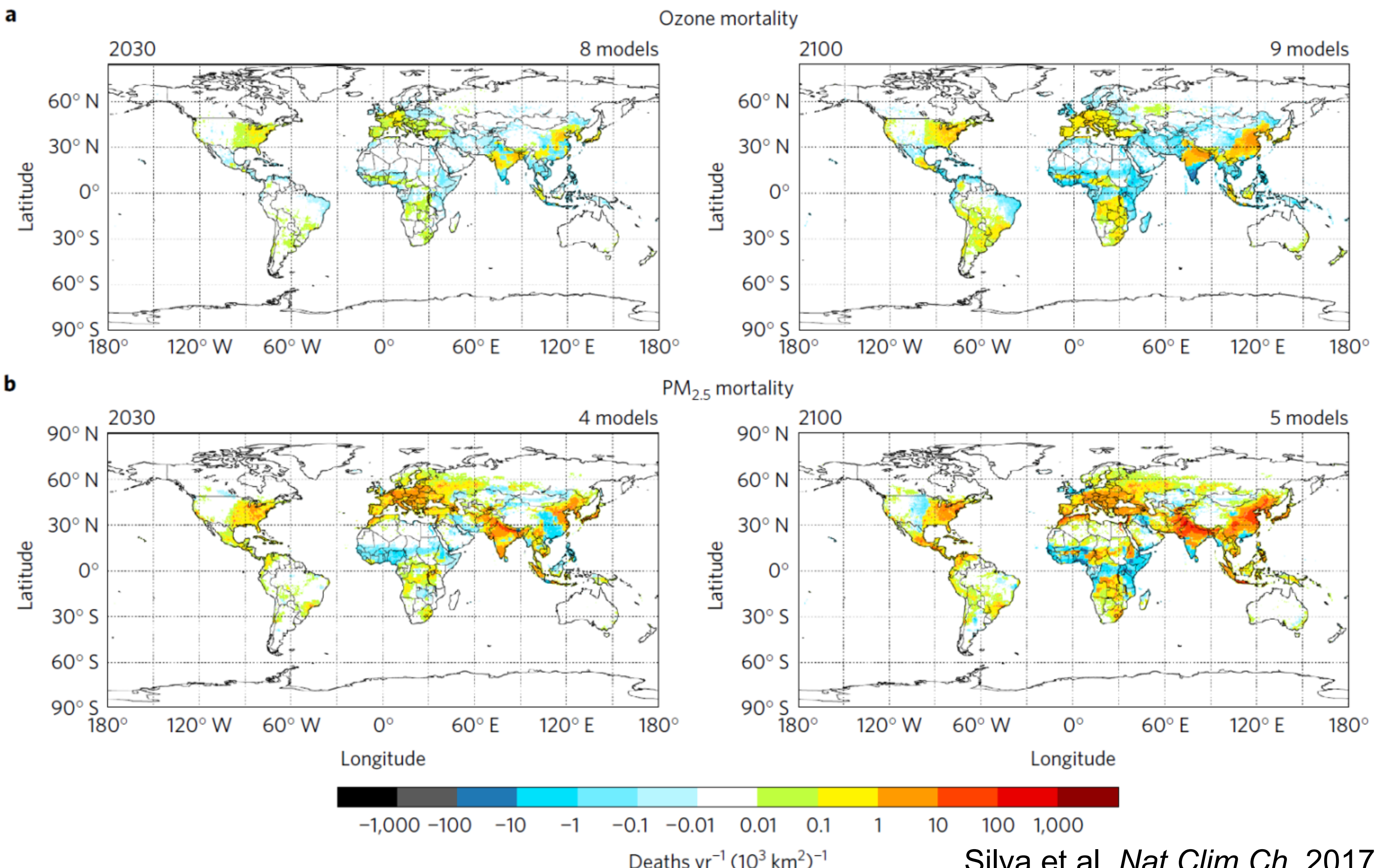
Mean (95% CI)
(deaths yr^{-1})

2030
56,000
(-34,000 , 164,000)

2100
215,000
(-76,000 , 595,000)

Silva et al. *Nat Clim Ch*, 2017

Impact of RCP8.5 Climate Change on Global Air Pollution Mortality: ACCMIP Models



Silva et al. *Nat Clim Ch*, 2017

UNC GILLINGS SCHOOL OF GLOBAL PUBLIC HEALTH

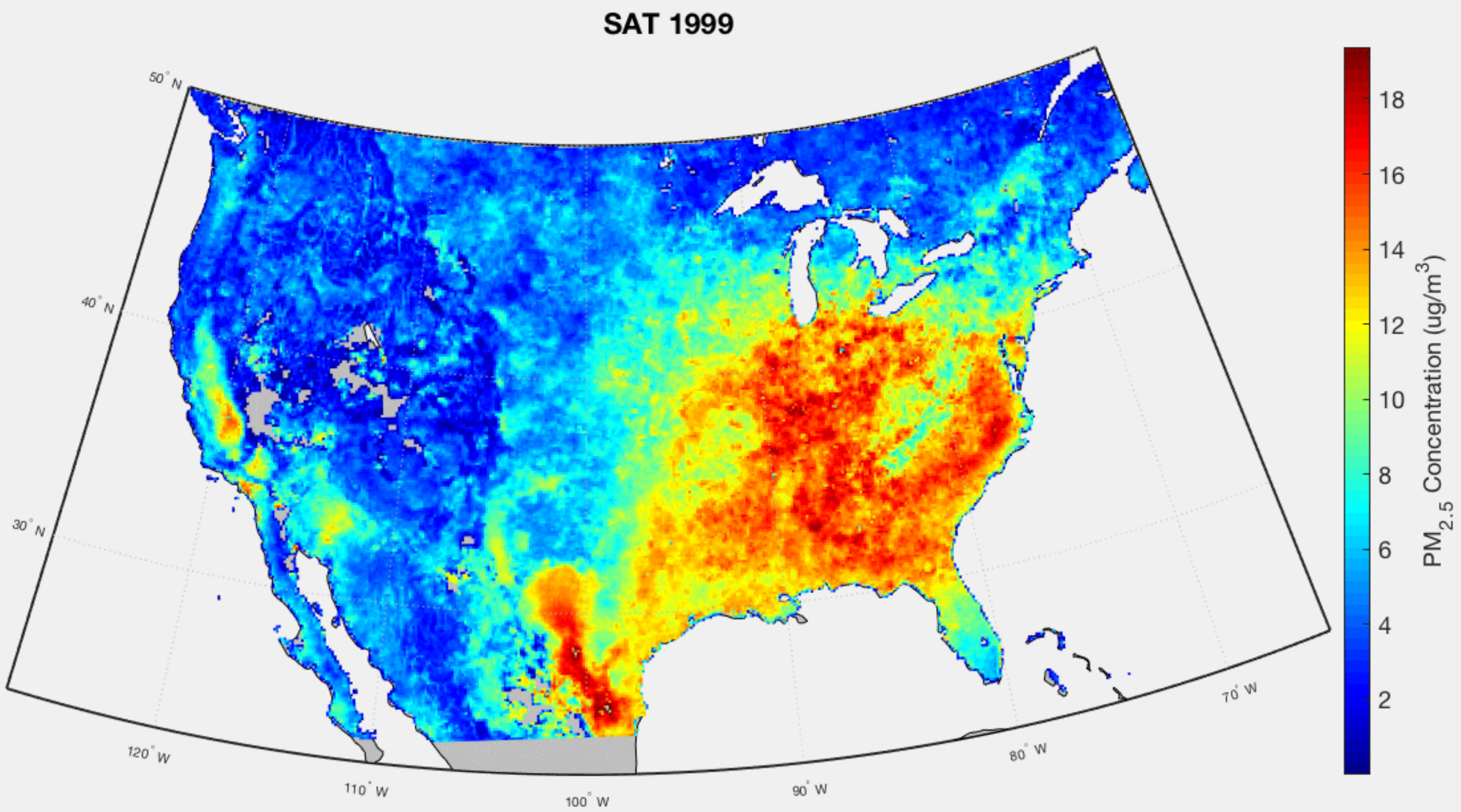
Health Benefits of Decreases in $PM_{2.5}$ and Ozone in the United States, 1990-2015

Omar Nawaz, Yuqiang Zhang, Daniel Q. Tong, Aaron van Donkelaar, Randall Martin, J. Jason West

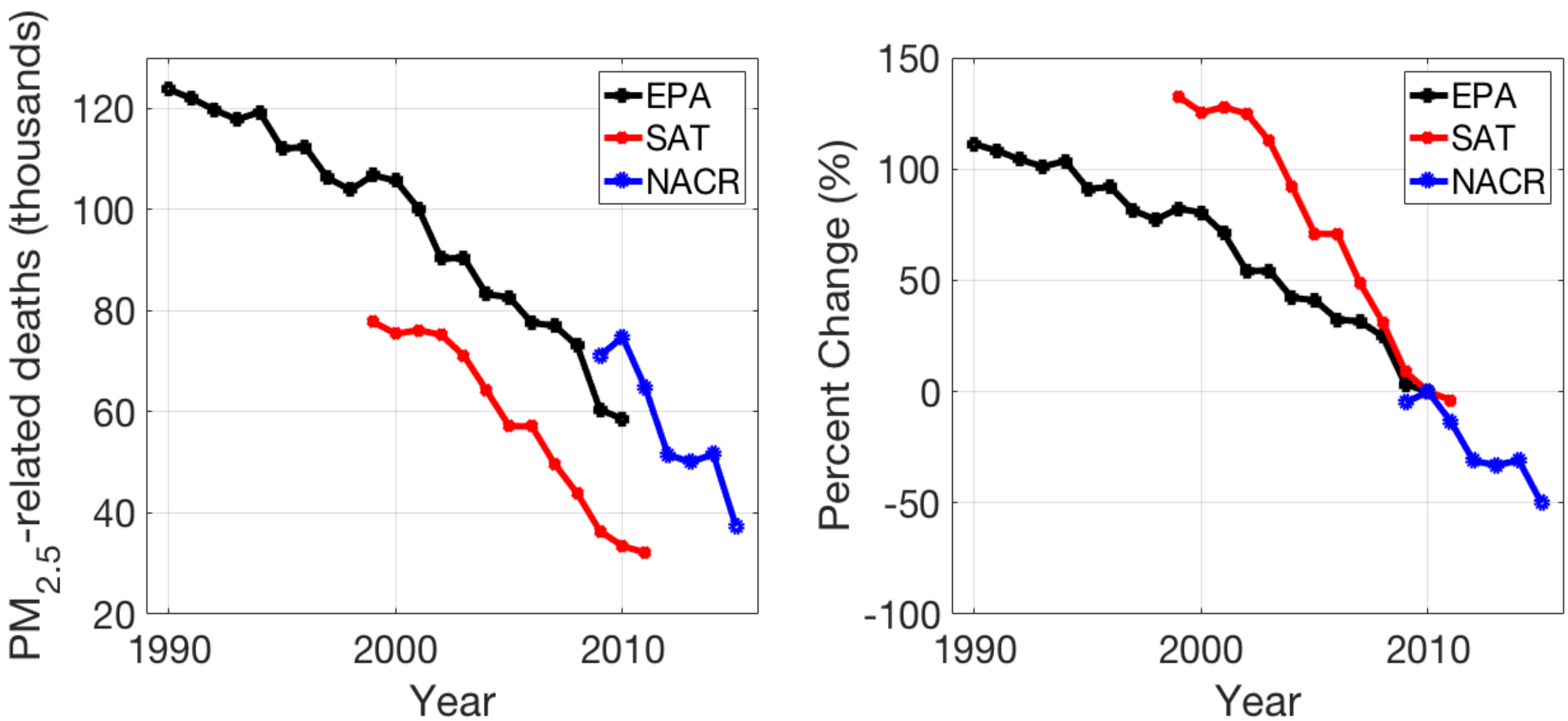
* Air pollutant datasets:
  - A 21-year CMAQ simulation (1990-2011) **EPA**
  - The North American Chemical Reanalysis (2009-2015) **NACR**
  - N. America $PM_{2.5}$ satellite-derived data combined with a model and surface observations (1999-2012) **SAT**

* We use annual county-level population and baseline cause-specific mortality rates from the CDC to assess air pollution mortality in each year.

Trends in $PM_{2.5}$ (SAT)

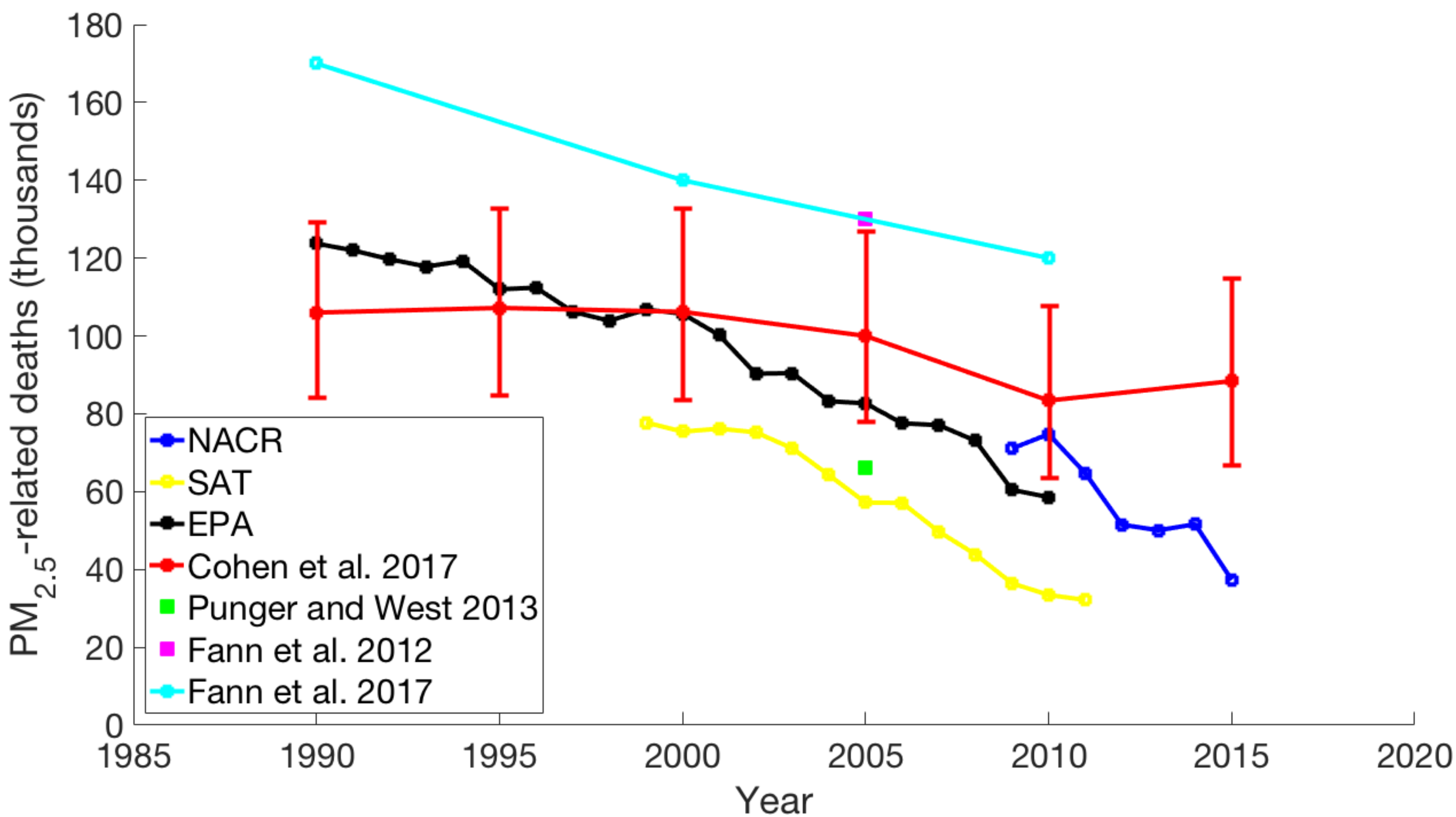


US $PM_{2.5}$-related deaths



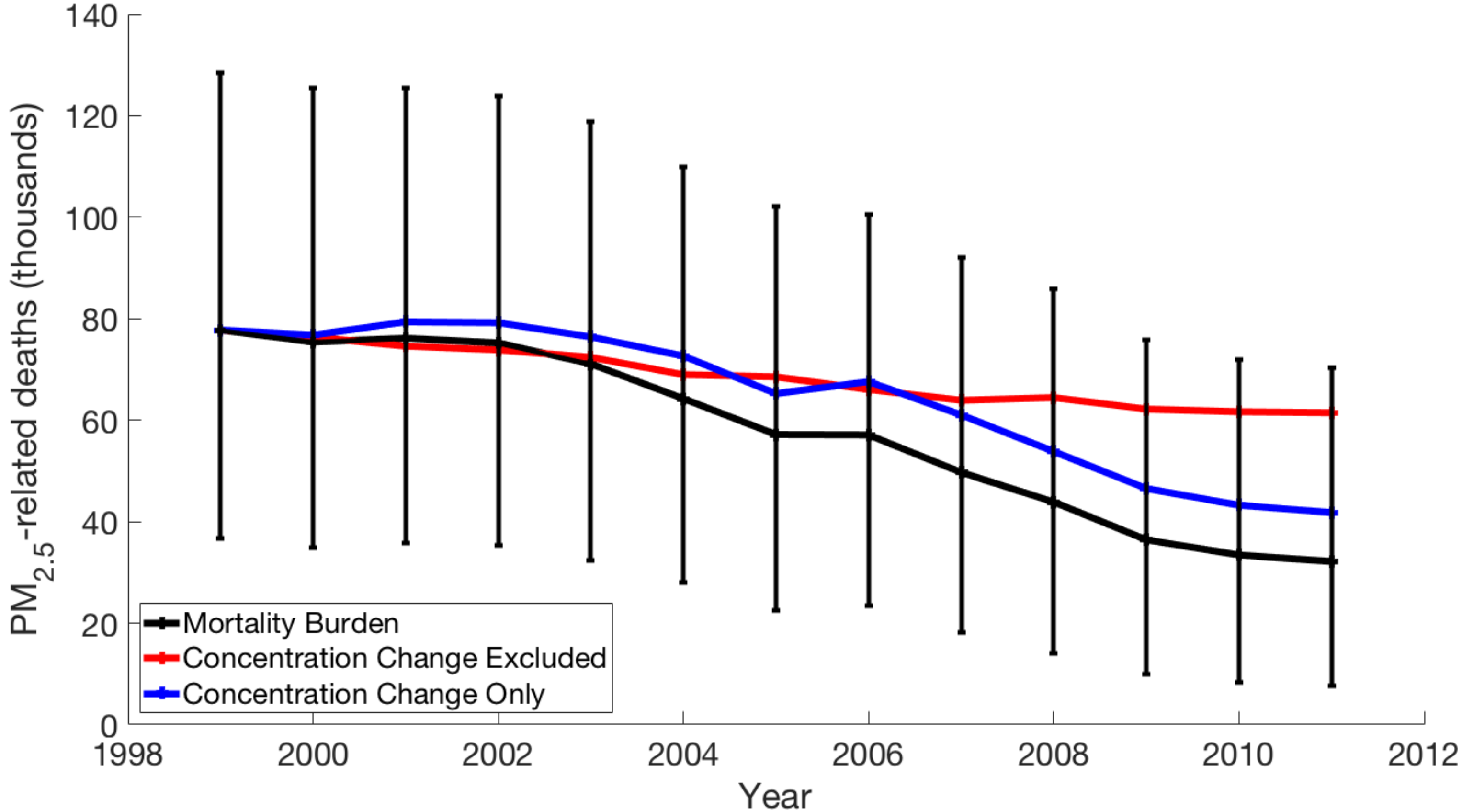
Zhang, ACP 2018; Nawaz, in prep.

Comparison with Other Studies ($PM_{2.5}$)



Zhang, ACP 2018; Nawaz, in prep.

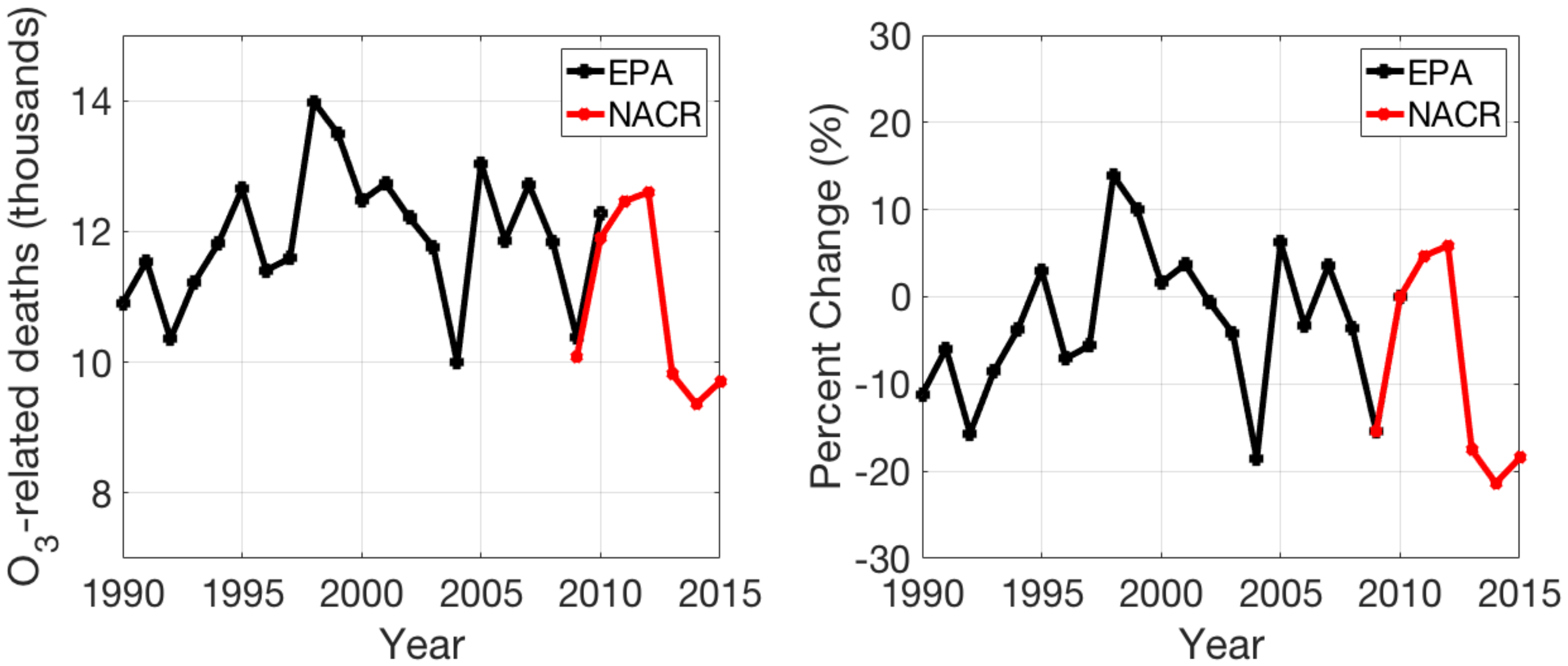
$PM_{2.5}$ Mortality Burden (SAT)



We estimate that **29400** deaths were avoided in **2011** from lower $PM_{2.5}$ concentrations

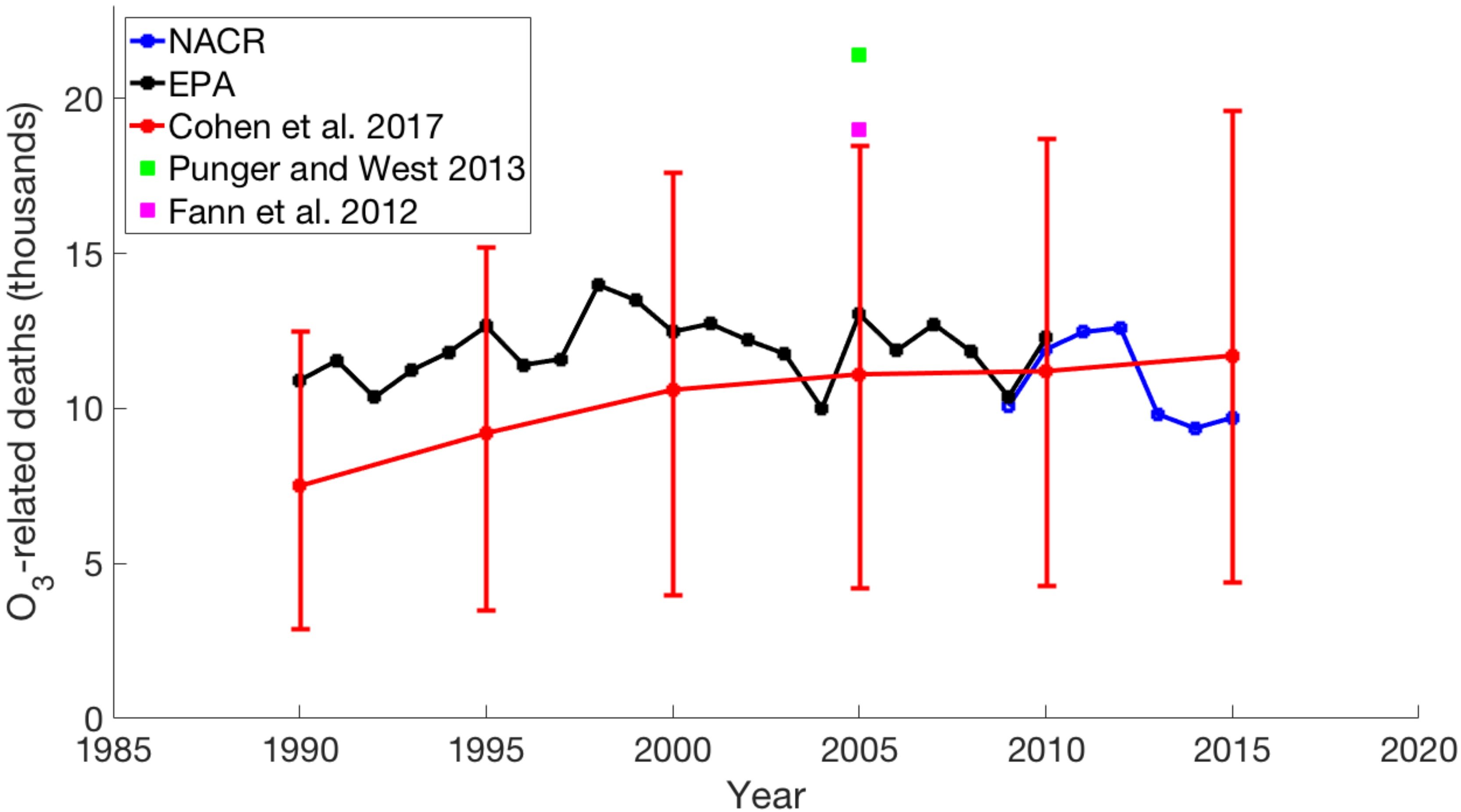
Zhang, ACP 2018; Nawaz, in prep.

US O_3-related deaths



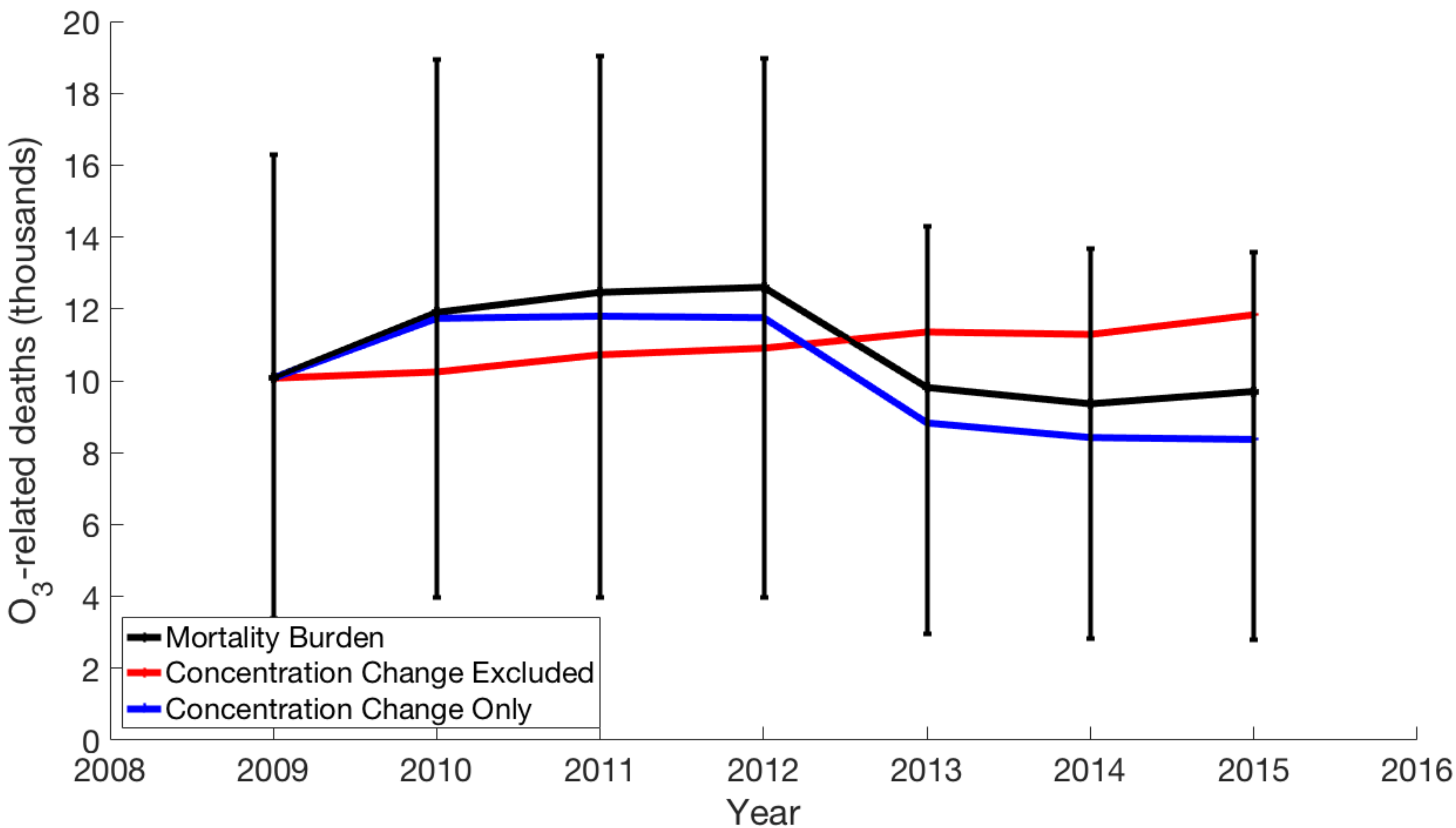
Zhang, ACP 2018; Nawaz, in prep.

Comparison with Other Studies (O_3)



Zhang, ACP 2018; Nawaz, in prep.

O_3 Mortality Burden



We estimate that **2100** deaths were avoided in **2015** from lower O_3 concentrations

Which kills the most in the US?

A) Air pollution
B) All gun shootings
C) All traffic accidents
D) AIDS

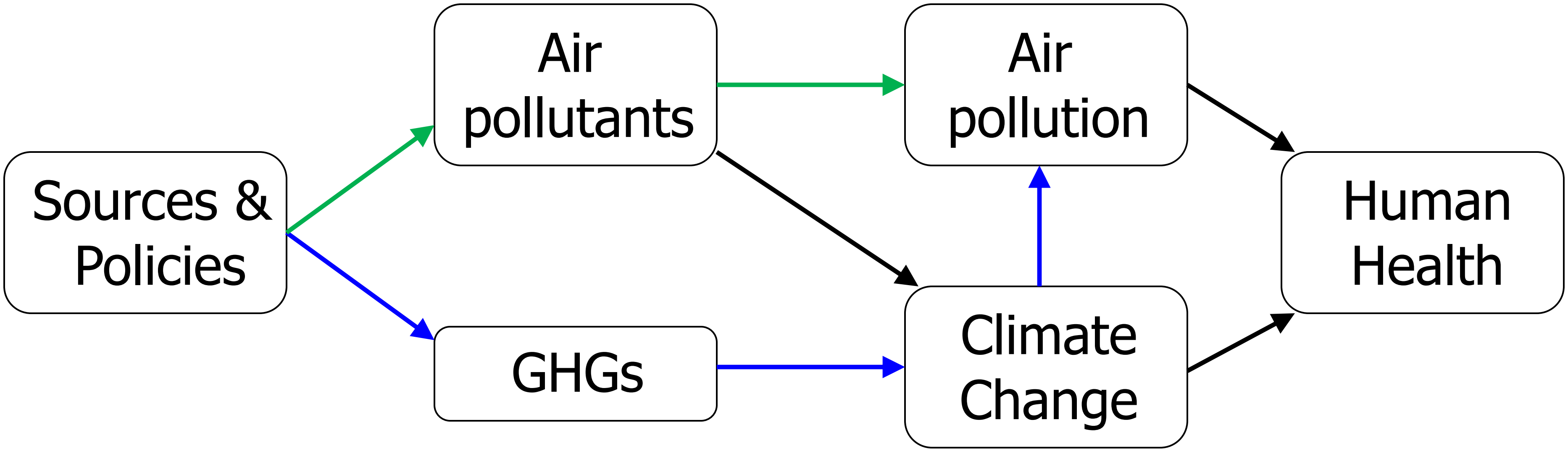
Which kills the most in the US?

A) Air pollution	**47,000**
B) All gun shootings	**36,300**
C) All traffic accidents	**36,200**
D) AIDS	**6,200**

Air Pollution is responsible for 1 in 58 deaths in the US.

Co-benefits of GHG Mitigation for Air Quality

1) Immediate and Local



2) Long-Term and Global

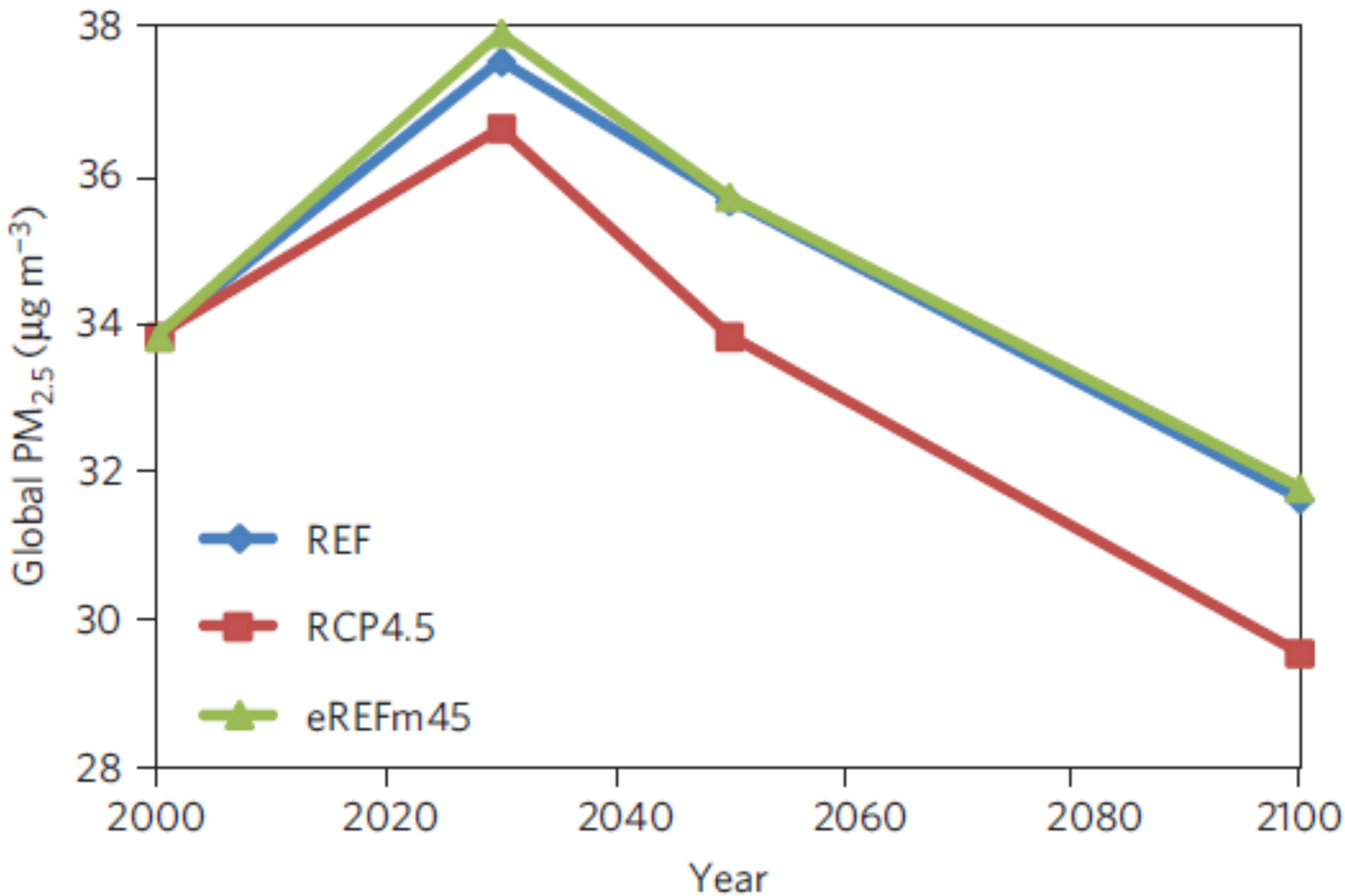
Objective: Analyze global co-benefits for air quality and human health to 2100 via both mechanisms.

Approach

Years	Emissions GCAM	Meteorology GFDL AM3	Name
2000	2000	2000	2000
2030, 2050, 2100	GCAM Reference	RCP8.5	REF
	RCP4.5	RCP4.5	RCP4.5
	GCAM Reference	RCP4.5	eREFm45

- Use the GCAM reference for emissions rather than RCP8.5, for consistency with RCP4.5.
- Simulations conducted in MOZART-4.
  - 2° x 2.5° horizontal resolution.
  - 5 meteorology years for each case.
  - Fixed methane concentrations.
  - Compares well with ACCMIP RCP4.5.

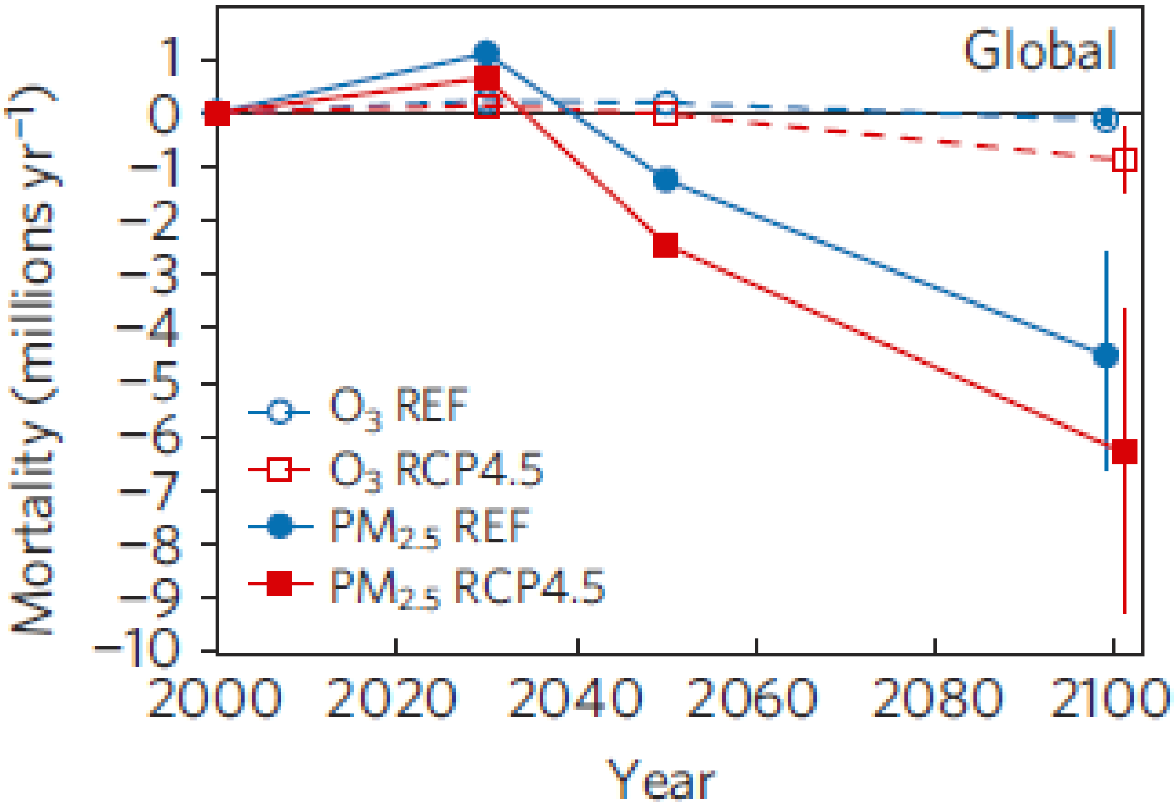
Co-benefits – $PM_{2.5}$ Concentration



Global population-weighted, annual average $PM_{2.5}$

West et al. *Nat. Clim. Ch.* 2013

Co-benefits – Global Premature Mortality



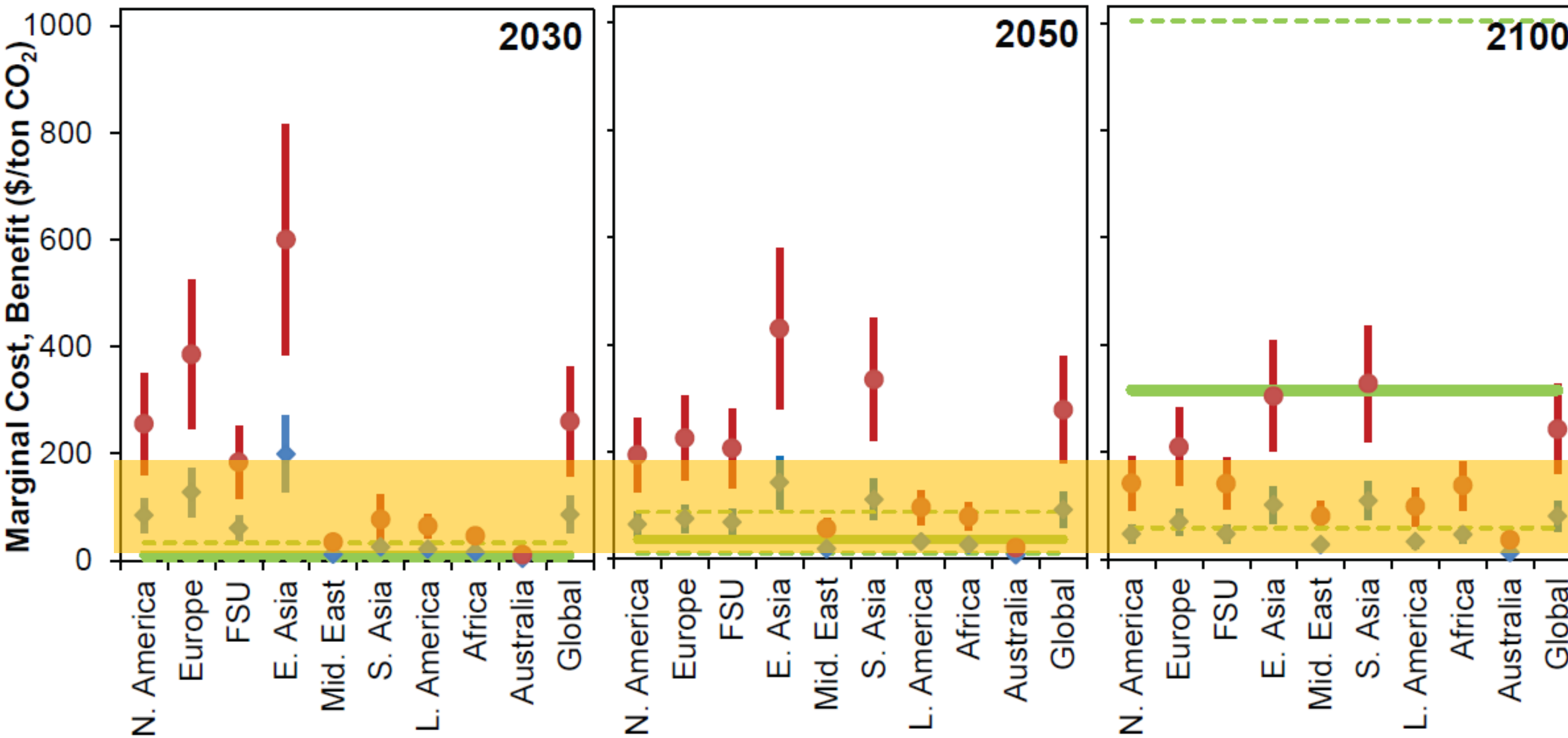
Projection of global population and baseline mortality rates from International Futures.

$PM_{2.5}$ co-benefits
(CPD + lung cancer mortality)
2030: 0.4±0.2 million yr^{-1}
2050: 1.1±0.5
2100: 1.5±0.6

Ozone co-benefits
(respiratory mortality)
2030: 0.09±0.06
2050: 0.2±0.1
2100: 0.7±0.5

West et al. *NCC* 2013

Co-benefits – Valuation of Avoided Mortality



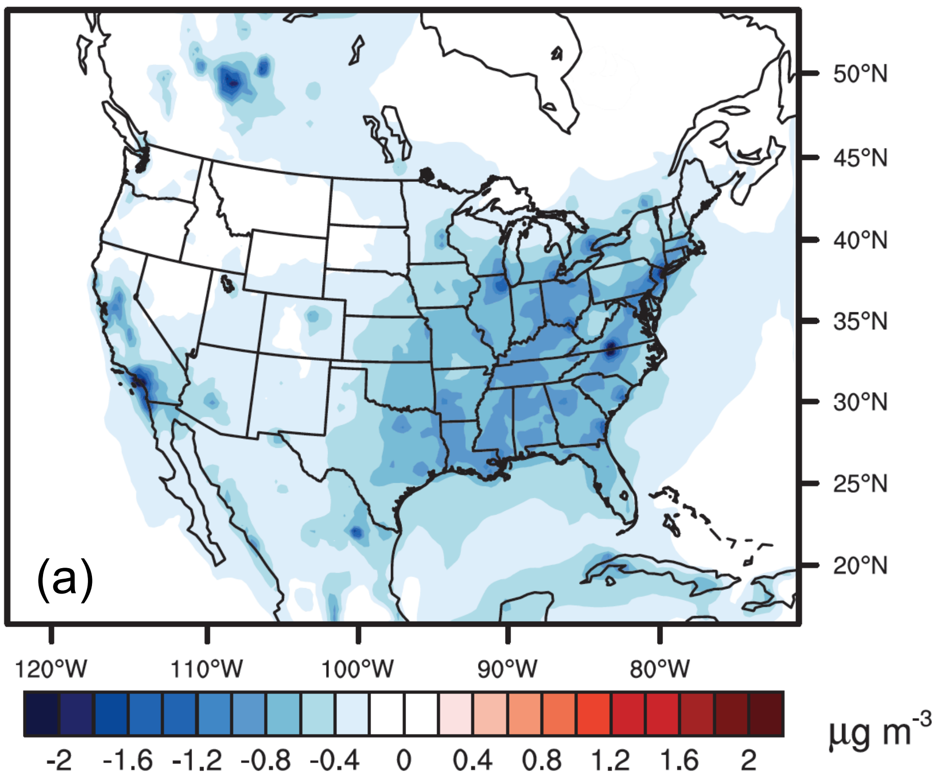
Red: High valuation (2030 global mean $3.6 million)
Blue: Low valuation (2030 global mean $1.2 million)
Green: Median and range of global C price (13 models)

West et al. *Nat. Clim. Ch.* 2013

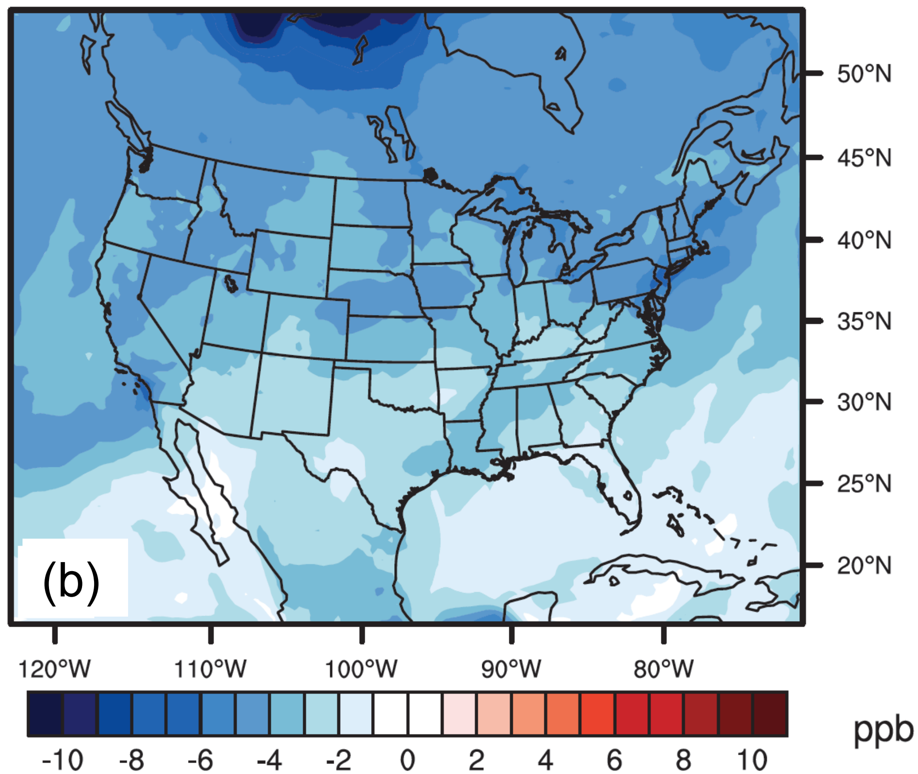
Downscaling Co-benefits to USA (2050)

RCP4.5 - REF

PM$_{2.5}$ (annual avg.)
US mean = 0.47 μg/m^3

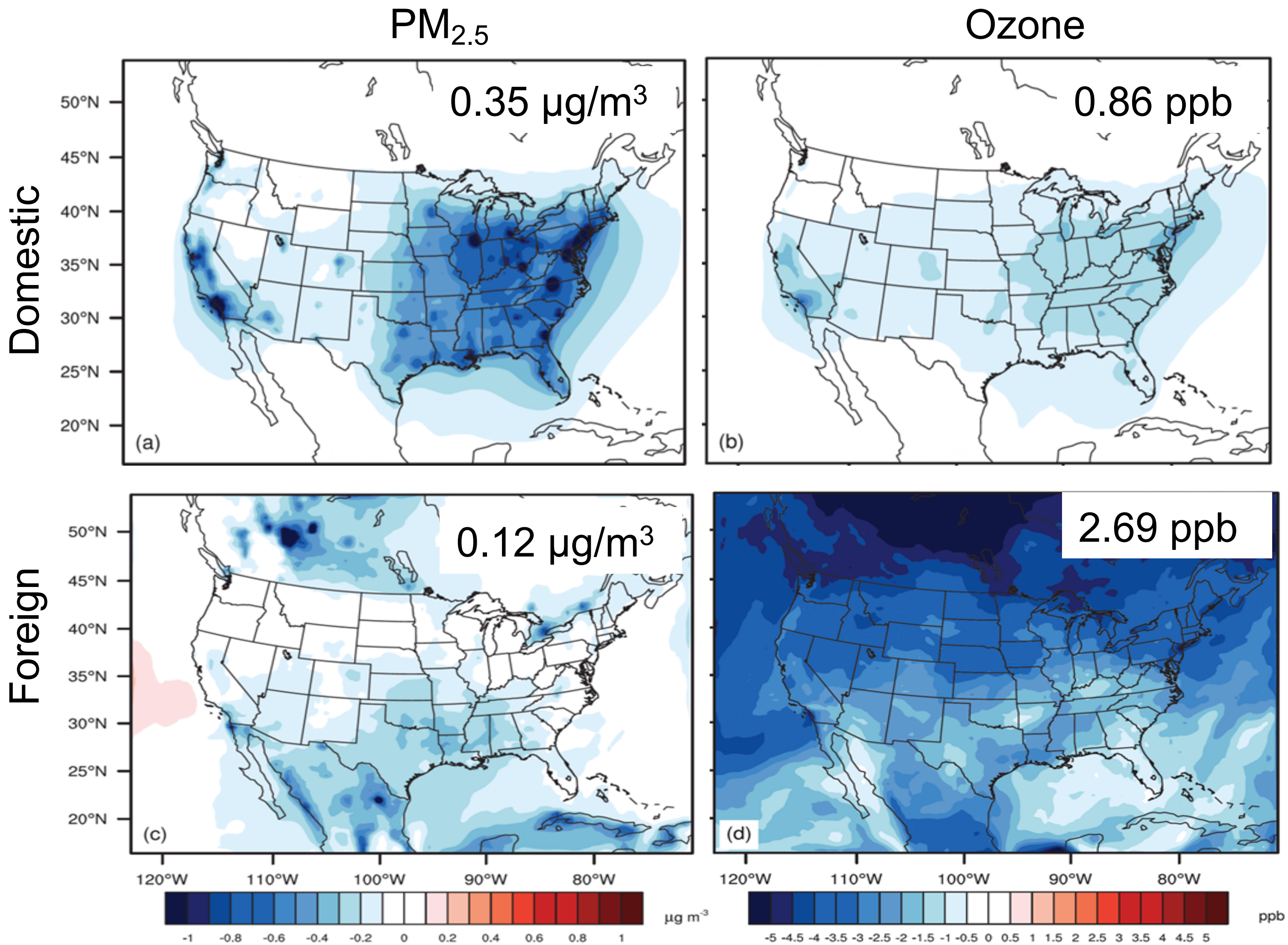


Ozone (May-Oct MDA8)
US mean = 3.55 ppbv



Zhang et al. ACP, 2016

Downscaling Co-benefits to USA (2050)



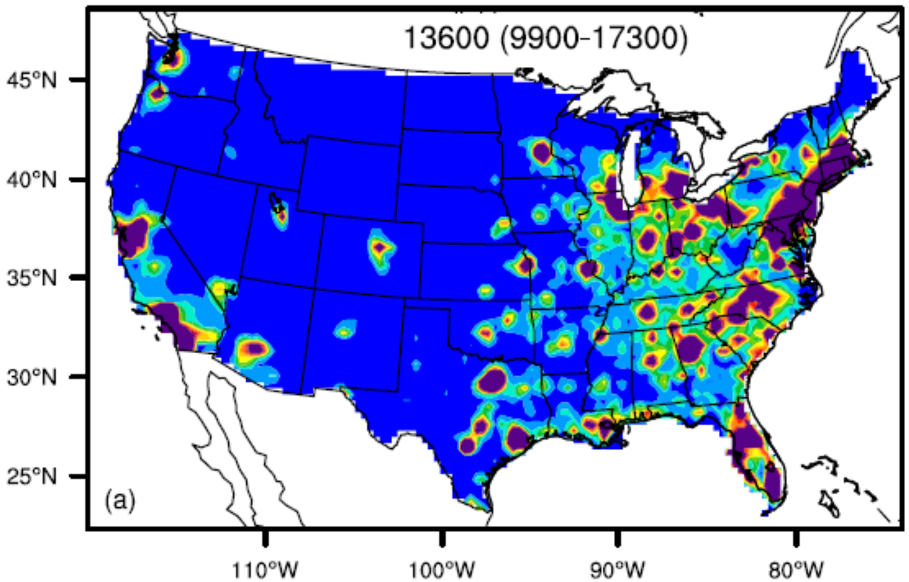
Most PM$_{2.5}$ co-benefits from **domestic** reductions.

Most ozone co-benefits from **foreign** and **methane** reductions.

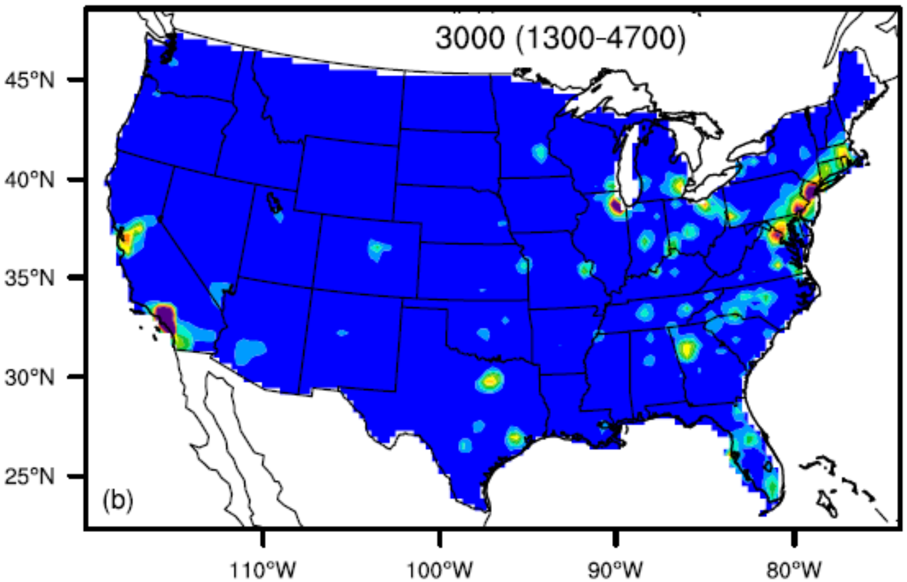
Zhang et al. ACP, 2016

Domestic vs. Foreign Co-benefits: $PM_{2.5}$

Domestic



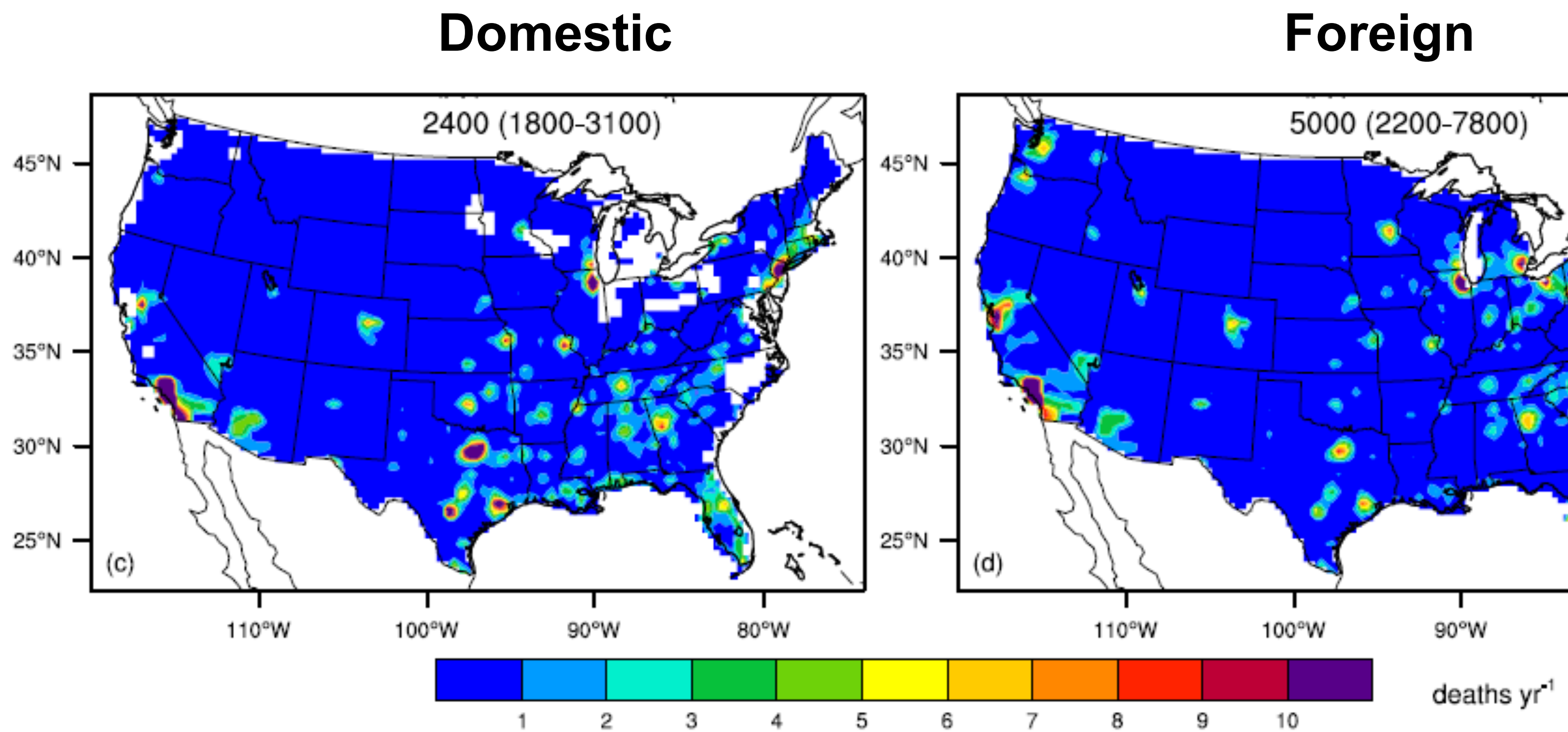
Foreign



- Domestic GHG mitigation accounts for 85% of the total avoided $PM_{2.5}$ mortality.

Zhang et al. *ERL* 2017

Domestic vs. Foreign Co-benefits: O_3



- Foreign countries' GHG mitigation accounts for 62% of the total avoided deaths of O_3.

Zhang et al. *ERL*, 2017

US Co-benefits in 2050

- **Avoided premature deaths** from GHG mitigation: 16000 (CI: 11700-20300) from $PM_{2.5}$, and 8000 (CI: 3600-12400) from O_3.
- **Avoided heat stress mortality** from RCP4.5 relative to RCP8.5: 2340 (CI: 1370-3320) (Ying Li).
- Monetized co-benefits in 2050 are $49 (32-67) per ton CO_2 reduced at low VSL, $148 (96-201) at high VSL.
- **Foreign GHG mitigation** accounts for 62% of the total avoided deaths from O_3, and 15% for $PM_{2.5}$.
- Previous regional or national co-benefits studies may **underestimate** the full co-benefits of coordinated global actions.
- U.S. can gain significantly greater co-benefits, especially for ozone, by **collaborating with other countries** to combat climate change.

Zhang et al. *ERL*, 2017; Li et al in preparation

Thank you

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